DEPARTMENT OF

SCIENTIFIC AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

THE CENTRAL ENGLAND DISTRICT

(*SECOND EDITION, REVISED*)

by

F. H. EDMUNDS, M.A.

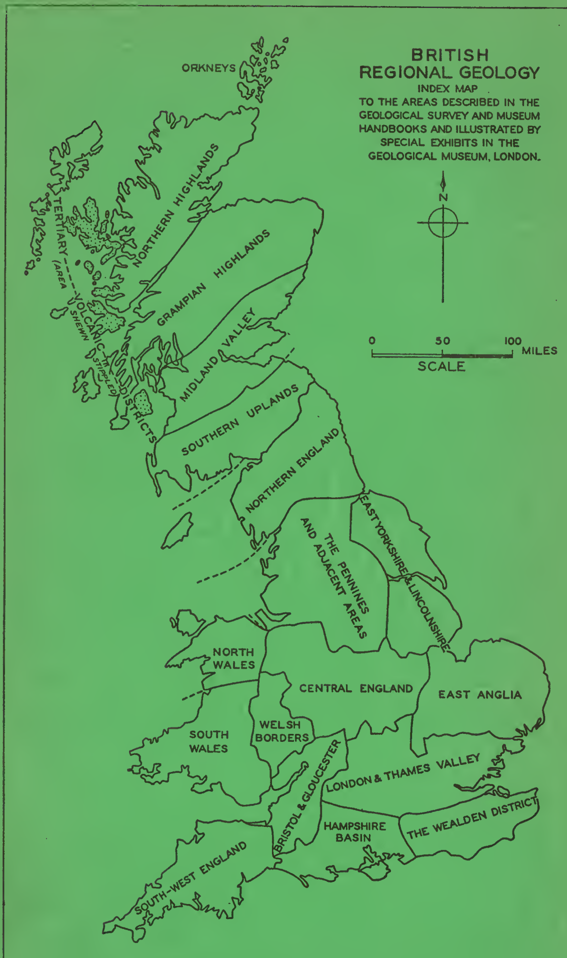
and

K. P. OAKLEY, B.Sc., Ph.D.

LONDON

HER MAJESTY'S STATIONERY OFFICE

SIX SHILLINGS NET


BRITISH
REGIONAL GEOLOGY
INDEX MAP
TO THE AREAS DESCRIBED IN THE GEOLOGICAL SURVEY AND MUSEUM HANDBOOKS AND ILLUSTRATED BY SPECIAL EXHIBITS IN THE GEOLOGICAL MUSEUM, LONDON.
N
0
50
100
MILES
SCALE
ORKNEYS
NORTHERN HIGHLANDS
TERTIARY VOLCANIC DISTRICTS
(AREA SHEWN STIPPLED)
GRAMPIAN HIGHLANDS
MIDLAND VALLEY
SOUTHERN UPLANDS
NORTHERN ENGLAND
THE PENNINES AND ADJACENT AREAS
EAST YORKSHIRE & LINCOLNSHIRE
NORTH WALES
CENTRAL ENGLAND
EAST ANGLIA
SOUTH WALES
WELSH BORDERS
BRISTOL & GLOUCESTER
LONDON & THAMES VALLEY
HAMPSHIRE BASIN
THE WEALDEN DISTRICT
SOUTH-WEST ENGLAND

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH
GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

THE CENTRAL ENGLAND DISTRICT

(SECOND EDITION, REVISED)

By

F. H. EDMUNDS, M.A.

and

K. P. OAKLEY, B.Sc., Ph.D.

STY

CONTENTS

First Edition 1936
Second Edition 1947
Eighth impression with minor emendations 1958
Ninth impression 1963

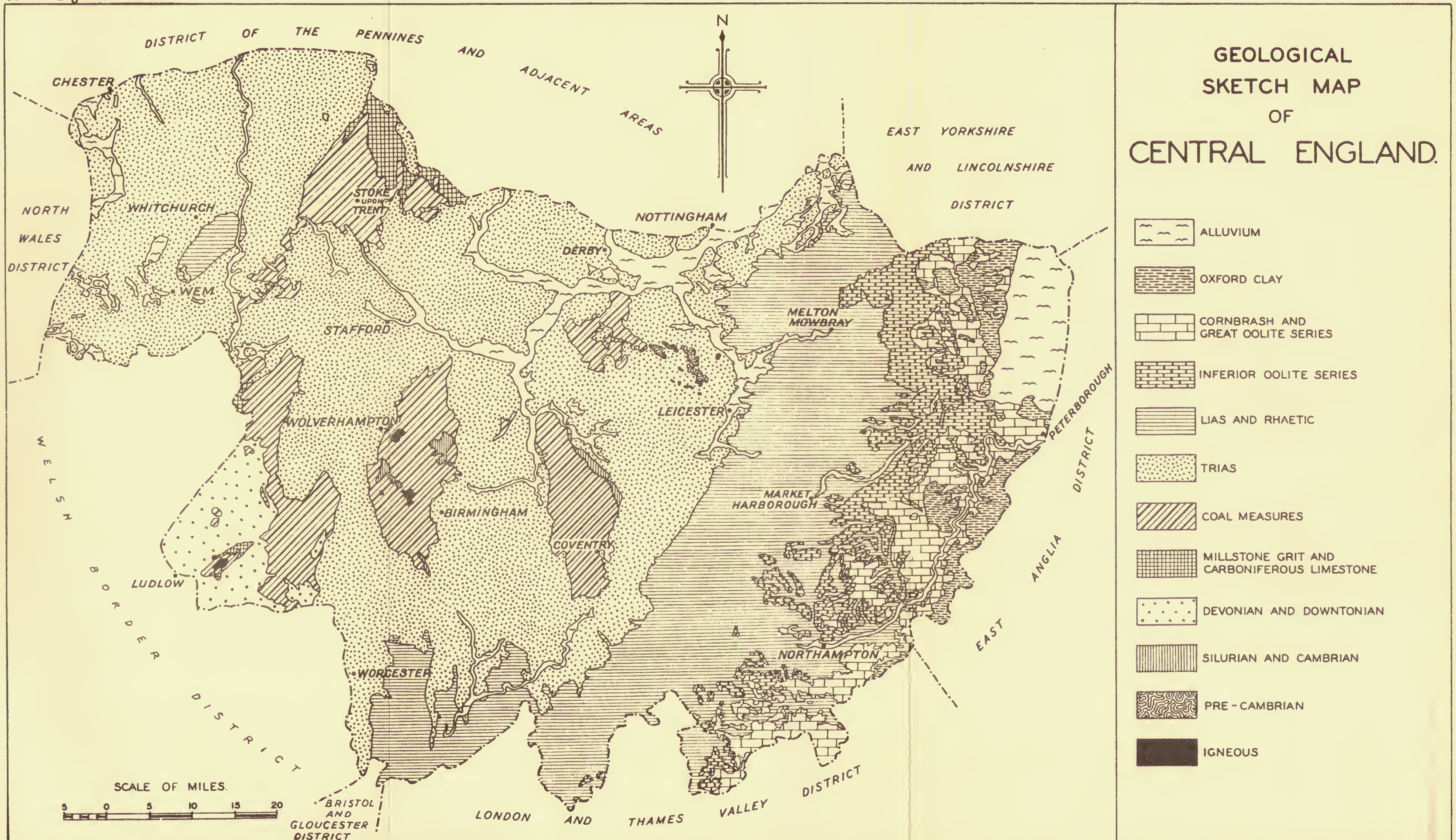
LIST OF ILLUSTRATIONS

FIGURES IN TEXT

PLATES

The numbers in brackets are those of the corresponding Geological Survey photographs, copies and prices of which may be obtained on application.

The Geological Survey is indebted to the late Professor W. W. Watts, F.R.S., for the photograph by W. J. Harrison, Plate IIA, and for permission to reproduce Plate VB.



6672-2848-2,500-11/58 (M.F.P.)

THE CENTRAL ENGLAND DISTRICT

I. INTRODUCTION

THE CENTRAL ENGLAND district embraces the counties of Northamptonshire Leicestershire, Rutland, Warwickshire and Staffordshire, and parts of Derbyshire, Nottinghamshire, Worcestershire, Cheshire, Flintshire and Shropshire. Its area, which is arbitrarily delimited, is indicated on the sketch-map, Plate I.

The physical features of the region call for little comment. The northern part includes the major portion of the great Central Plain of England, a comparatively flat region which is, however, broken locally by slightly more elevated tracts; the southern part is gently undulating. The greater part of the country lies below the 400-ft. contour, and with but few exceptions the remainder is below 1,000 ft. The Clent Hills attain a height of 1,036 ft.; north of Stoke-upon-Trent the ground reaches 1,102 ft.; and the Clee Hills rise to 1,790 ft. The northern part of the district is drained mainly by the River Trent and its tributaries; the River Severn flows through the western part; and the eastern and south-eastern parts are drained by the Rivers Nene and Welland.

Although generally of low elevation, the district shows marked contrasts in type of country. The strata of the Central Plain contain deposits of coal, fire-clay, gypsum, salt, and iron ore; all of great economic importance. As a consequence highly industrialized areas, comprising the Potteries and the Black Country and including Birmingham, Coventry and Stoke-upon-Trent, have developed. The southern part is almost wholly of a pastoral character, although in recent years the exploitation of important iron-ore deposits in Northamptonshire, Rutland and Leicestershire has been changing the character of some localities.

The rocks exposed at the surface are almost wholly of sedimentary character, but igneous rocks of various ages and types occur in some places, notably in Charnwood Forest, at Rowley Regis, and near Nuneaton. All geological systems from Pre-Cambrian to Upper Jurassic, with the exception of the Ordovician, are represented at the surface. The sequence of strata is given in the 'Table of Formations,' p. 4.

Our detailed knowledge of the geology of Central England is of comparatively recent date. Indeed, before 1850 little work had been done in the area; a number of geologists, however, are outstanding for their researches on isolated districts. Robert Plot, in 1686, published a 'Natural History of Staffordshire,' in which he described Coal Measures in some detail, and attempted a certain amount of correlation, from which he deduced the fact that the different strata were arranged as 'several folds of divers consistencies still including one another, after the manner of the coats of a *pearl,* or an *onyon,*' thus indicating one of the first principles of stratigraphy. He described numerous rocks, and figured a number of crystals and fossils.

In 1808 John Farey published a geological section, showing the arrangement of strata between Derbyshire and the coast of Lincolnshire. William Smith's geological maps were issued in 1815. Strickland covered a wide field in his researches, including Drifts, the Lias and the Trias, during the twenties of the last century. In 1829 Yates described the Hartshill and the Lickey quartzites and the associated intrusive rocks, and concluded that they were of Silurian age.[1] In 1839 Murchison gave a comprehensive account of the geology of Shropshire, Worcestershire and Staffordshire in his 'Silurian System.' Brodie described fossils from the Lias of the Midlands in 1857.

Systematic work on the district was initiated by the Geological Survey. It has been remarked above that Central England is a region of much mineral wealth; as a consequence early Survey memoirs were primarily of an economic nature, dealing in particular with coalfields. Between the years 1850 and 1880 hand-coloured geological maps covering practically the whole area were published on the scale of one inch to a mile, the first being part of Sheet 61, issued in 1850. These maps, of the 'Old Series,' have been gradually superseded by 'New Series' maps, on the same scale, but colour-printed; the first New Series Sheet for the Midlands was that of Atherstone, Sheet 155, published in 1898. Each map of the latter series is accompanied by an explanatory memoir.

Many Geological Survey memoirs have appeared from time to time: in 1859 were published Beete Jukes' account of the South Staffordshire Coalfield, and a similar work by Howell on the Warwickshire Coalfield. In 1860 Hull's 'Geology of the Leicestershire Coalfield' appeared, and during 1886–1891 several volumes by Aveline, with whom Trench and Howell collaborated, were issued; these dealt with the geology of parts of Northamptonshire, Leicestershire, Warwickshire and Nottinghamshire. Since that date numerous economic memoirs have been published, dealing with subjects such as Gypsum, Rock-salt, Iron Ore, Coal, Refractory Minerals and Water Supply; contributors to this series include H. B. Woodward, G. W. Lamplugh, C. B. Wedd, J. Pringle, B. Smith, T. C. Cantrill, R. L. Sherlock, L. Richardson and H. Dewey.

In 1900 the first memoir to be associated with a New Series map of the Midlands appeared, viz. 'The Geology of the Country between Atherstone and the Charnwood Forest,' by C. Fox-Strangways and W. W. Watts. Contributors to later memoirs of this series include G. W. Lamplugh, W. Gibson, C. B. Wedd, B. Smith, G. Barrow, R. W. Pocock, D. A. Wray, T. Eastwood, T. H. Whitehead, T. Robertson, G. H. Mitchell, C. J. Stubblefield and R. Crookall.

Organized work in Central England by geologists other than those of the Geological Survey staff may be considered to have commenced about 1886. In that year the British Association visited Birmingham, and general interest in the geology of the Midlands was kindled by Charles Lapworth, whose outstanding work is the foundation of our knowledge of the Pre-Cambrian and Cambrian formations in the Midlands. The relationships of these formations to each other were described in accounts of the geology of the Birmingham District contributed to the Handbooks of the British

[1] At that time the term 'Silurian' had a wider significance than it has to-day.

Association for both the 1886 and 1913 meetings. Since 1886 much research work has been carried out under the auspices of the Geological Department of Birmingham University, under the successive direction of Professors Lapworth, W. S. Boulton, L. J. Wills and F. W. Shotton. The numerous papers of Beeby Thompson have added greatly to our knowledge of the Jurassic formations. Other workers who have made valuable contributions to our knowledge of Midland geology include T. G. Bonney, T. O. Bosworth, E. S. Cobbold, W. J. Harrison, V. C. Illing, R. Kidston, W. Wickham King, F. Raw, L. Richardson, F. W. Shotton, H. H. Swinnerton and W. W. Watts.

The results of the various researches have appeared in the Quarterly Journal of the Geological Society, the Proceedings of the Geologists' Association, the Geological Magazine, and in proceedings and transactions of several Natural History Clubs, notably the Journal of the Northants Natural History Society, Proceedings of the Warwickshire Naturalists' Field Club, Proceedings of the Cotteswold Naturalists' Field Club, Transactions of the Worcestershire Naturalists' Club, Proceedings of the Birmingham Natural History and Philosophical Society, Proceedings of the Leicester Literary and Philosophical Society, Midland Naturalist and publications of the Caradoc Field Club.

With few exceptions the fossils and rocks mentioned or described in the following pages are shown in the special CENTRAL ENGLAND EXHIBIT in the Geological Museum, Exhibition Road, S. Kensington.

Table of Formations Present in the Central England District

Representatives of the following formations are exposed at the surface.

Quaternary	Recent and Pleistocene (Superficial Deposits)	Alluvium; Fen Deposits; River Gravels; Boulder Clay; Glacial Gravels; Glacial Lake Deposits.		
Tertiary or Cainozoic (Intrusive Igneous Rocks only)				
Mesozoic or Secondary	Jurassic	Oxford Clay, with Kellaways Beds in lower part		
		Cornbrash		
		Great Oolite Series	Great Oolite Clay and Forest Marble	
			Great Oolite Limestone	
			Upper Estuarine Series	
		Inferior Oolite Series	Lincolnshire Limestone, with Collyweston Slate	
			Lower Estuarine Series	
			Northampton Sand with Ironstone	
		Lias	Upper Lias	
			Middle Lias, with Marlstone	
			Lower Lias	
		Rhaetic		
	Triassic	Keuper Series	Keuper Marl (including Upper Keuper Sandstone)	
			Lower Keuper Sandstone	
		Bunter Series	Upper Mottled Sandstone	
			Pebble Beds	
			Lower Mottled Sandstone	
Palaeozoic or Primary	Permian	possibly represented by the Enville Beds		
	Carboniferous	Coal Measures	Upper Coal Measures (Barren Measures)	Enville Beds (? Permian)
				Keele Beds
				Newcastle Group
				Etruria Marl
				Blackband Ironstone Group
			Middle Coal Measures (Productive Measures)	
			Lower Coal Measures	
		Millstone Grit Series		
		Carboniferous Limestone Series (including Lydebrook and Cornbrook Sandstones)		
	Devonian (Old Red Sandstone)	Upper Old Red Sandstone		
		Lower Old Red Sandstone		

Palaeozoic or Primary	Silurian	Downton (of Old Red Sandstone facies)	Ledbury Group Temeside Group
		Ludlow	Upper Ludlow Beds Aymestry (or Sedgley) Limestone Lower Ludlow Shales
		Wenlock	Wenlock (or Dudley) Limestone Wenlock Shales Woolhope (or Barr) Limestone
		Upper Llandovery	Rubery Shales Rubery Sandstone
	Ordovician	(igneous rocks only)	
	Cambrian	Stockingford Shales	Merevale Shales (Tremadoc Series) Oldbury Shales (excluding Abbey Shales= Lingula Flag Series) Purley Shales
		Hartshill Quartzite	Camp Hill Grit Tuttle Hill Quartzite Park Hill Quartzite
Pre-Cambrian or Archaean	Charnian	Brand Series Maplewell Series Blackbrook Series	
	Uriconian	Caldecote Volcanic Series Lilleshall and Barnt Green rocks	

Ordovician, Cretaceous and Tertiary sedimentary strata are absent from Central England. Igneous rocks include Pre-Cambrian porphyries and ' syenites ' of Charnwood Forest, the supposed Ordovician ' diorites ' of Nuneaton, the Mount Sorrel granite, intrusive and extrusive rocks of Carboniferous age in Leicestershire and South Staffordshire and extrusive rocks of similar age in Shropshire and North Staffordshire. Intrusive rocks of Tertiary age occur in North Staffordshire and in Shropshire.

II. PRE-CAMBRIAN SYSTEMS

THE OLDEST KNOWN rocks of our district pre-date the earliest fossiliferous rocks, and are termed 'Pre-Cambrian.' In Central England these are for the most part deeply buried beneath newer rocks, but here and there movements of folding and faulting, together with denudation, have produced exposures of them at Nuneaton, at Lilleshall, in the Lickey Hills and in Charnwood Forest.

It is probable that in the Midlands at least two distinct systems of Pre-Cambrian rocks are represented. The Charnian System, comprising the rocks of Charnwood Forest, may be of the same age or older than the Eastern Longmyndian System in Shropshire. The rocks of Lilleshall, Barnt Green, the Wrekin and Nuneaton (Caldecote) are referred to the Uriconian System, which takes its name from the Wrekin Hill (*see* 'The Welsh Borderland,' *Brit. Reg. Geol.*), from the name of which, in its Celtic form, the Roman city of *Uriconium* was called. No definite conclusion as to the relative ages of the Uriconian and Longmyndian Systems has been reached. Evidence on the point is very conflicting, and at least six views have been propounded.

Our picture of Pre-Cambrian times is a very imperfect one, from lack of evidence, but by the researches of Bonney, Watts, Bennett and others into the Charnwood rocks, some insight has been gained into the history of a small part of the Pre-Cambrian aeon; this may be summarized as follows:—

At times a shallow sea covered part of the Central England region. There is abundant evidence of contemporary volcanic activity, and the ejected products of the volcanoes fell into the sea and so became sorted and stratified. After the earlier deposits had been buried beneath later accumulations, and compacted into hard rocks, they were invaded by the deep-seated molten material of which the earlier volcanoes had been a surface manifestation. The crustal instability of the region reached its culmination in the folding and faulting of compacted Charnian sediments towards the end of Pre-Cambrian times. Subsequently the region became dry land, and a long period of subaerial erosion preceded invasion by the Cambrian sea.

Uriconian Rocks

The Uriconian System comprises a series of intrusive and pyroclastic (p. 7) rocks. Those of Nuneaton, termed the Caldecote Volcanic Series, have a narrow outcrop, nearly two miles long but not more than 300 yards in width, which occupies the north-eastern flank of the Hartshill ridge. They are overlain unconformably by Cambrian quartzite.

The Caldecote rocks consist mainly of volcanic material sorted and stratified under water, and include purple and green laminated ashes and grits and crystal tuffs.

Associated with them are other igneous rocks believed to be of the same general age. These include a fine-grained dolerite ('basalt'), which was formerly exposed in the 'Blue Hole' quarry, and a quartz-felsite which shows signs of pene-contemporary brecciation suggestive of an extrusive origin.

At Lilleshall, two miles south of Newport, Pre-Cambrian rocks are brought to the surface in a small narrow faulted inlier along the western margin of the Coalbrookdale Coalfield. At the northern end of the outcrop they give rise to the steep-sided eminence of Lilleshall Hill, the long axis of which makes an angle with the general strike of the beds, a feature which appears to be characteristic of Uriconian outcrops.

The distribution of pebbles of Uriconian type in the Enville Beds of Staffordshire and Warwickshire (*see* p. 50) indicates that Uriconian rocks may underlie a large part of the south-central Midlands. The only outcrop of Uriconian rocks in that part of the region is at Barnt Green, at the southern end of the Lickey Hills, where a series of volcanic ashes and grits, closely resembling those of Caldecote and Lilleshall, come to the surface in a small wedge-shaped inlier. These rocks form a slightly elevated area, and are faulted against the Cambrian quartzite which crops out immediately to the north. Like the Pre-Cambrian rocks of Caldecote and Lilleshall, they are intersected by basic intrusions of doubtful, probably of Ordovician, age. None of these outcrops is sufficiently large to be shown on the Sketch-map, Plate I.

THE ROCKS OF CHARNWOOD FOREST

In Charnwood Forest, Pre-Cambrian rocks are exposed in a series of irregular outcrops which in all cover an area of over 17 square miles. Charnwood Forest is a picturesque upland area, some 35 square miles in extent, which rises abruptly above the low-lying central plain to a general elevation of over 500 ft., while the highest point, Bardon Hill, reaches an altitude of 912 ft. One of the features of the region is the great diversity of scenery. The typical pastoral landscape of Central England is found side by side with rugged fir-covered country. The reason for these contrasts lies in the geology, for the hard Pre-Cambrian rocks form isolated eminences projecting through the softer Trias. The folded and compacted Pre-Cambrian rocks constituted part of a mountain range in Permian and Triassic times; these mountains were gradually worn down and ultimately buried beneath the desert deposits of the Triassic period. Erosion has partly removed this Triassic cover, and the summits of pre-Triassic mountains are again being revealed. Where the Trias remains, the soil is thick and fertile and the scenery is of pastoral type; where the pre-Triassic mountain slopes have been swept clean there is an abrupt change to a rugged terrain with craggy outcrops (Plate II A).

The Pre-Cambrian rocks of Charnwood include extrusive and intrusive igneous rocks and sediments composed of volcanic ashy material. In some cases these sediments represent igneous products accumulated above sea level, but the majority were formed of volcanic ashes sorted out and stratified in the water of a shallow sea. They are termed 'Pyroclastic' (Gk. *pyr*, fire, *clastos*, broken or fractured); the sedimentary rocks are probably equivalent in age to the Grey or Eastern Longmyndian of Shropshire.

CHARNIAN PYROCLASTIC ROCKS

These have a great thickness difficult to estimate and have been subdivided by Professor Watts as follows:

Brand Series		Swithland and Groby Slates Conglomerate, grit and quartzite Purple and green striped slates
Maplewell Series	Upper	Olive Hornstones of Bradgate Park Woodhouse Ashes
	Lower	Slate Agglomerate of Roecliffe Beacon Hill Hornstones Felsitic Agglomerate
Blackbrook Series		Hornstones (*i.e.* silicified ashes) and tuffs

These series roughly correspond with stages of a volcanic cycle. The Blackbrook Series represents a period of mild but prolonged activity; vulcanicity reached its maximum intensity by Lower Maplewell times, but declined during the accumulation of the Upper Maplewell beds; at the time the Brand Series was being laid down activity had much diminished, and previously formed deposits were then undergoing erosion and redeposition.

The Charnian rocks of the southern and central parts of the Forest have been studied in greater detail than those in the north-western area, which extends from Timberwood to Grace Dieu Park. The succession is obscured in the Grace Dieu Park district partly on account of considerable disturbance of the strata through faulting, but mainly owing to the fact that the actual focus of volcanic activity was situated in that region.

STRUCTURE OF CHARNWOOD FOREST

Towards the close of Pre-Cambrian times the Charnian rocks were folded into a great elongated dome trending N.W.–S.E. Subsequent erosion has removed the greater part of the dome, so that the inclined beds now form a nearly elliptical outcrop. The northern half of the denuded dome is obscured by Triassic material. In the main, the beds are seen to dip north-east and south-west of a line running through St. Ives Head, Ling Dale and Holdgate Lodge. The essentially anticlinal structure of the region was perceived nearly a hundred years ago by both Sedgwick and Jukes.

Although the general structure is simple, extensive faulting has introduced numerous complications. The earth-movements which raised the Charnwood anticline also led to actual dislocation of the strata. Numerous fractures occurred parallel to the axis of the fold, and later at right angles to the axis, the flanks of the anticline being thrust inwards. An important line of anticlinal faulting extends through Bawdon Castle, Benscliffe, and Hallgate Hill Spinney. West of this line other thrust-faults have led to repetition of beds at the surface. The Felsitic and Slate Agglomerates provide a good key to the detailed structure, for they are persistent beds, and being highly resistant to erosion stand out as prominent ridges the continuity of which is broken by the cross-faults.

Whereas the main uplift of the Charnwood fold and the greater part of the faulting and the cleavage of the beds are attributable to late Pre-Cambrian movements, it is often difficult to distinguish the original structures from those produced by later movements along the original lines of weakness.

IGNEOUS ROCKS

The oldest intrusive rocks in the Charnwood region are the so-called 'porphyroids,' which are almost confined to the north-western area. The term 'porphyroid' is here misapplied, for the large crystals which are a common feature of these rocks were the result of primary crystallization, and not of re-crystallization through metamorphism, as the name originally implied. These Charnian rocks comprise various igneous types, including dacites, toscanites and diorite porphyries. They are mostly regarded as intrusive rocks; some may be plugs filling old volcanic vents, but others may be lava-flows. They are approximately contemporary with certain of the Charnian pyroclastic rocks, for fragments exactly similar to some of the porphyroids are found in the coarse Charnian agglomerates. Furthermore, the porphyroids show the same deformation as the pyroclastic rocks. Some of them, for example the High Sharpley porphyroid, have been intensely sheared and crushed by the late Pre-Cambrian movements. Typical examples crop out at High Tor, Peldar Tor, High Sharpley and Grimley.

Intrusive masses of 'syenite' occupy considerable areas. They fall into two main groups or types, a southern, comprising the intrusive bosses of Markfield, Bradgate and Groby, and a northern and central group, including intrusions with rather narrow linear outcrops, such as those of Hammercliffe and Bardon Castle.

These syenites, of a variety now termed markfieldite, are crystalline rocks consisting of felspar phenocrysts and chlorite (replacing hornblende and occasionally augite) set in a fine micrographic intergrowth of felspar and quartz. The southern type is green and pink in colour whereas the northern type is predominantly grey and is more basic in composition. Professor Watts has found that the northern group has been less affected by earth-movements than the southern and for this reason he suggests that they were intruded at a slightly later stage.

The fact that the Charnwood syenites show similar tectonic structures to those of the pyroclastic rocks is a strong presumption in favour of their being Pre-Cambrian in age, and the strength of this presumption is increased by the recognition, by Wills and Shotton, of the similarity in all essentials to the markfieldite type of Charnwood of boulders of syenite in a bed at the base of the Cambrian quartzite at Nuneaton. The mass from which the boulders have been detached is clearly intrusive in the Caldecote Series and forms part of the immediate sub-Cambrian surface.

Isolated masses of plutonic rock emerge from beneath the Trias to the south of Charnwood Forest, at Enderby, Croft, Narborough, Stoney Stanton, Sapcote, etc. With the exception of the Narborough rock, which is a dark red felsite, these bosses are somewhat similar to the Charnwood syenites; that they are of Pre-Cambrian age, however, is not accepted by all geologists.

Quartz-felsites, probably Pre-Cambrian in age, have been struck beneath the Trias in deep bores at Orton and Oxendon Hall in Northamptonshire.

THE MOUNT SORREL GRANITE

A large intrusive boss of granite (grano-diorite), over a mile in diameter, occurs at Mount Sorrel, emerging from beneath the Trias in isolated irregular outcrops. For convenience this mass is here considered along with the older igneous rocks of Leicestershire, but its age is uncertain. It is probably later than the main Charnian syenites, since it has not been involved in the N.W.–S.E. movements which affected them, and its joint-system is entirely different; moreover, an associated diorite at Kinchley invades slates which probably belong to the Swithland group—the highest member of the Charnian pyroclastic sequence. Since it is cut by dolerite dykes which appear to belong to the Carboniferous suite its age is probably pre-Carboniferous. It is possible that it is of Devonian age, and it may be associated with the Caledonian earth-movements.

The Mount Sorrel granite is a coarsely crystalline rock of uniform texture, varying in colour from reddish-brown to light grey.

At the south-western edge of the outcrop there is a small intrusion of quartz-mica-diorite, and at Kinchley Hill, on the eastern bank of the Swithland reservoir, the contact between the two occurs. The inclusion at the junction of detached portions of the diorite in the granite shows that the latter is the younger. At Brazil Wood, an island in the middle of the Swithland Reservoir, the diorite has invaded Charnian slates and the heat of the molten injection has metamorphosed the slates into a mica-garnet-hornfels.

The Charnian plutonic rocks and the Mount Sorrel granite are extensively quarried for setts, road-metal and for the manufacture of artificial stone.

III. CAMBRIAN SYSTEM

THE BEGINNING OF the Cambrian period was marked by the gradual spreading of a shallow sea over a land-mass formed of folded and compacted Pre-Cambrian rocks which had been reduced to a low relief by erosion.

Large quantities of coarse sandy sediment were at first deposited in this sea, and in places shore-line erosion led to the formation of beaches. Calcareous deposits accumulated later under rather clearer water conditions. The sands are now converted into sandstones and quartzites, the beach-deposits into conglomerates and the calcareous muds into thin beds of limestone.

As the old land-mass became more completely submerged only fine sediments accumulated. Thus, over most of the Midland area the sandy deposits of the Lower Cambrian sea were succeeded by muds. The latter now forms shales and mudstones which constitute the bulk of the Cambrian succession. The accumulation of this thick series of marine deposits indicates a slow subsidence of the area. At no time, however, does the sea appear to have been deep; non-sequences in deposition, and the occurrence of sandy, glauconitic and phosphatic layers in the shale-series, indicate that the sediments occasionally came under the influence of tidal scour, and that the movements of depression were discontinuous.

In Shropshire and Central England the Cambrian rocks attain a thickness of about 4,000 ft., but this is small in comparison with the maximum thickness of the formation in North Wales, which is estimated at about

18,000 ft. The North Welsh deposits were accumulated in a relatively rapidly down-sagging region, whereas those of the Midland province were formed on the fringe of a slowly-sinking extensive land mass.

In the present area Cambrian rocks are exposed only in small inliers at Lilleshall, Nuneaton, Dosthill (near Tamworth), and in the Lickey Hills, but evidence from various bore-holes shows that they have a wide underground distribution.

The ridge constituting the Lower Lickey Hills, south-west of Birmingham, is formed of a thick mass of quartzite which is folded along a N.N.W.–S.S.E. anticlinal axis, and is much crumpled and faulted. This Lickey Quartzite is greyish-white in colour, coarse grained, and unfossiliferous. It closely resembles the Lower Cambrian Quartzite of Warwickshire.

At Lilleshall there is a small inlier of unfossiliferous Comley Sandstone (the Shropshire facies of the Lower and Middle Cambrian).

The most important Cambrian rocks are those of the Warwickshire Coalfield. This coalfield may be regarded as an up-faulted block with a general synclinal structure; the oldest rocks therefore crop out along the two faulted margins. Inliers of Cambrian rock occur on the west at Dosthill, two and a half miles south of Tamworth, and on the east, near Nuneaton. The Nuneaton inlier, in addition to being the largest outcrop of Cambrian rocks in the Midlands, provides a fuller sequence than do any of the others, and it furnishes, in attenuated form, the complete Cambrian succession; this succession is shown in Fig. 1. About nine miles long and attaining a maximum width of just over a mile, the Nuneaton inlier extends along the eastern border of the coalfield from Atherstone in the north to Bedworth in the south. Between Atherstone and Nuneaton the strike is N.W.–S.E., but farther south it changes to N.N.W.–S.S.E. It was not until Lapworth discovered fossils in the Stockingford Shales in 1882 that the Cambrian age of these beds was established, the unconformity between the Stockingford Shales and the Coal Measures being masked by conformity of strike.

The main mass of the Hartshill Quartzite consists of indurated pinkish-grey sandstones, which have assumed the character of quartzites, through the development of a cementing matrix of secondary silica. The quartzite is extensively quarried for road-metal; quarrying and crushing processes are assisted by the well-marked bedding and jointing of the rock. Manganese ore (pyrolusite) occurs locally in joints and pockets, and was formerly worked on a small scale.

A red sandy limestone near the top of the Hartshill Quartzite, the *Hyolithus* Limestone, has yielded pteropod-like molluscs, *Hyolithus* (*Orthotheca*) *de geeri* and *Coleoloides typicalis*, and primitive brachiopods, such as *Micromitra phillipsi*. Fragments of a similar fossiliferous limestone were found in Hopwas Breccia (*see* p. 53) encountered in a borehole at Nechells, Birmingham.

The Purley Shales are extremely fine-textured, mainly purple in colour with green and grey bands. Dr. Pringle and Professor Illing have found *Callavia* in a nodule bed near the base of these shales.

Detailed knowledge of the Middle Cambrian succession is due to the work of Professor Illing, who found rich trilobite faunas in the blue-grey laminated shales which, with tough siliceous mudstones, constitute the

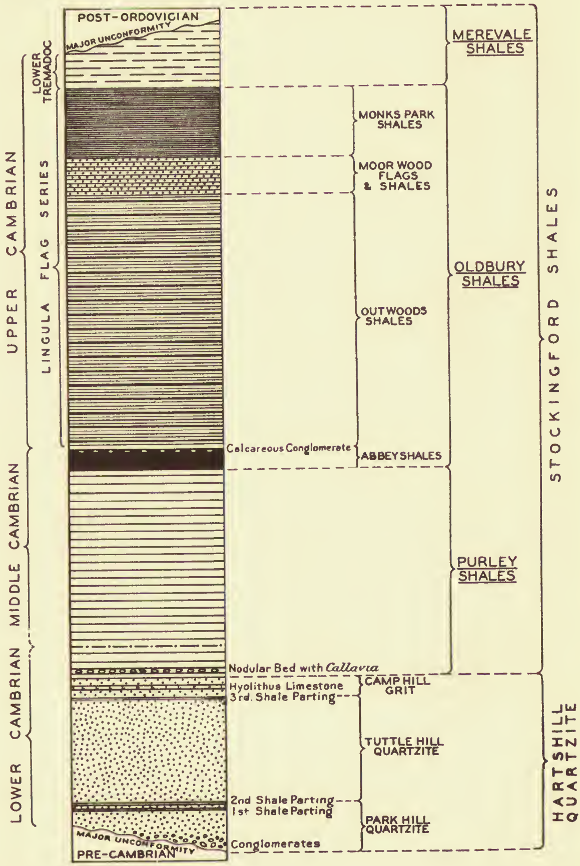


FIG. 1.—*Diagram showing the succession of Cambrian Rocks in the Nuneaton District*

Vertical Scale: One inch to 600 ft. approximately

Abbey Shales. He recorded amongst other fossils, *Paradoxides hicksi* and *P. davidis*, *Agnostus rex*, *A. barrandei*, *A. fissus*, *Eodiscus punctatus*, *Holocephalina incerta*, *Solenopleura applanata*, *Liostracus elegans* and *Hartshillia inflata*.

The Outwoods Shales, Moor Wood Flags and Monks Park Shales have been correlated with the three divisions of the Lingula Flag Series of Wales. They consist mainly of thin-bedded dark grey shales with layers of intensely black carbonaceous shale, but thick-bedded crumbly mudstones, flagstones and greenish shales occur at intervals. Fossils occur sparingly. Characteristic trilobites are *Olenus cataractes* and *Agnostus pisiformis*, var. *obesus* towards the base and *Sphaerophthalmus* near the top.

The Merevale Shales, green-grey in colour, have yielded fossils typical of the Tremadoc Series, such as *Dictyonema flabelliforme*, ? *Niobella homfrayi*, and *Shumardia pusilla*. Two characteristic Upper Cambrian fossils are shown in Fig. 2.

The Oldbury Shales also form a small faulted inlier on the western margin of the Warwickshire Coalfield at Dosthill.

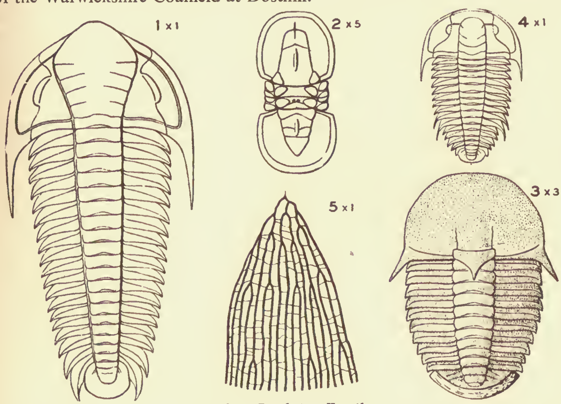


FIG. 2.—*Cambrian Fossils*

Middle Cambrian Beds.—1. *Paradoxides hicksi* Salter. 2. *Agnostus fissus* [Lundgren MS.] Linnarsson. 3. *Hartshillia inflata* (Hicks). Upper Cambrian Beds.—4. *Olenus cataractes* Salter. 5. *Dictyonema flabelliforme* (Eichwald).

The trilobite drawings are restorations based on specimens and published descriptions.

Occurrences of unfossiliferous shales of the same type as the Stockingford Shales have been recorded below the Trias in bores in other parts of Central England, at Market Bosworth, Sapcote and more doubtfully below boulder-clay at Elmsthorpe. These bores are situated on a line running N.W.–S.E. and it is suggested that they mark the axis of a sub-Triassic anticlinal ridge of older rocks running parallel to the Charnwood line of uplift. Black slaty rocks known to be of Tremadoc age have been found beneath the Trias on the line of the axis of the Charnian anticline itself at the Crown Hills boring near Leicester.

IGNEOUS ROCKS IN THE CAMBRIAN

In the Nuneaton district and at Dosthill the Cambrian strata have been cut by numerous sills of dark green hornblendic rocks showing considerable variation in texture, described as lime-bostonites, diorites, or camptonites. The sills vary in thickness from one to a hundred feet, and run parallel to the bedding for considerable distances, although they occasionally transgress from one bedding plane to another. In places they are numerous, both in the shales and in the quartzite. In some cases where the Stockingford Shales have been penetrated they have been baked and have acquired a prismatic cleavage in the neighbourhood of the contact.

Igneous rocks of the same type invade the Cambrian rocks in other parts of the country and have been encountered in bore-holes at Market Bosworth, Leicester and Calvert. The Merrylees drifts of the Desford Coal Company, completed in 1945, passed through Cambrian shales with intrusive sills for many yards. These igneous rocks are post-Tremadoc in age and various lines of evidence suggest that they were injected during the uplift of the Midland area which took place during the Ordovician period—a time of great igneous activity. The intrusion of this igneous material may have been connected with the downwarping of the crust which accompanied the development of the Ordovician geosyncline in the area to the north and west of the Central England Region.

The rocks form a valuable source of road-metal, and are extensively quarried at Dosthill, Hartshill, Nuneaton, Griff, and Marston Jabbett near Bedworth.

IV. SILURIAN SYSTEM

AT THE CLOSE of Cambrian times our region was uplifted to form part of a new land area which appears to have remained above sea level throughout Ordovician and earliest Silurian times, since no deposits of those periods are known in the district.

The later Silurian deposits, which occupy an important place in the geology of the Western Midlands, are best considered in relation to the general conditions that obtained over other parts of the British area during Lower Palaeozoic times. The conditions of sedimentation were largely controlled by a geosynclinal sea, stretching in a S.W.–N.E. direction across the Welsh Borderland, Wales, North-Western England, and Southern Scotland. During Ordovician and Lower Llandovery times our region formed part of the land-area south-eastward of the sea, termed for convenience the ‘ Midland Land-Mass.’ At the beginning of Upper Llandovery times, however, a gradual swamping of this land-mass commenced. Accordingly, the oldest Silurian deposits in Central England belong to the Upper Llandovery formation; they rest on an eroded surface of Cambrian rocks.

The Upper Llandovery Series consists of fossiliferous sandstones and silty shales deposited in the shallow waters of a transgressing sea. In the

Midlands the basal sandstones of the series appear to lap round the ridges of older rocks which formed at that time an irregular coast-line with deep embayments. With further submergence the ridges were no doubt reduced to islands and finally disappeared below the sea.

Three stages in the progressive swamping are shown in the palaeogeographical maps, Fig. 3.

As the sea spread eastwards, the littoral deposits of the Upper Llandovery were succeeded by calcareous muds which are now represented by the Wenlock and Ludlow Series. The newly submerged area formed a submarine shelf, and the shelly deposits of the shallow sea which covered it strongly contrast with the silty and graptolitic muds which accumulated in the deeper waters to the west. The line separating the shallow water deposits from those laid down in deeper water approximately coincides with that of a fault system through Church Stretton which may have been foreshadowed in Silurian times by crustal movement. The Silurian deposits of Britain exhibit two main facies, a *graptolitic*, consisting largely of black shales deposited as muds in relatively deep water, and a *shelly* comprising sandy, muddy and calcareous beds laid down in shallow water bordering the Midland Land-Mass. Local intercalations of graptolitic shales occur in rocks of the shelly facies, and aid in the correlation of the two groups.

The succession of Silurian rocks in the Midlands provides an almost complete record of a ‘ cycle of sedimentation’. The cycle began with the invasion of a land area by a shallow sea. Then followed the gradual burial of the land-mass by the coastal sands of the Upper Llandovery, and later by the slightly deeper-water muds and limestones of the Wenlock and Ludlow Series, the cycle continuing with the final silting up of the sea by the estuarine silts and deltaic muds of the Downton Series, and concluded with the uplift of a new land-mass. The Downton Series, although provisionally classed as Silurian, appears to represent the commencement of Old Red Sandstone conditions in our region, and may be more conveniently dealt with in connexion with that formation (*see* pp. 24 *et seqq.*).

The main outcrop of the shelly facies of the Silurian deposits occurs in the Welsh Border District, although the same formations which are there so well displayed underlie a considerable part of the West Midlands, and have been exposed locally by the removal of newer rocks, so that they form a series of inliers. They have also been encountered in shafts and bores in intervening areas.

The Silurian rocks which crop out in the Welsh Borders dip south-eastwards under Old Red Sandstone and Coal Measures, but come to the surface in small inliers at Barrow, Willey and Linley, on the crests of small anticlines parallel to the strike of the main Shropshire outcrop. Again at Neen Sollars, near Cleobury Mortimer, they are exposed in a small faulted anticline, the axis of which has the same trend. Between the Coalbrookdale and South Staffordshire Coalfields the Silurian rocks lie deeply buried beneath Coal Measures and Trias. At Claverley, in the Forest of Wyre Coalfield, a borehole proved Silurian rocks at a depth of 2,190 ft.; but, in the Albynes borehole, near Bridgnorth, they were struck at 220 ft.; They rise nearer to the surface again near Trimpley and Heightington,

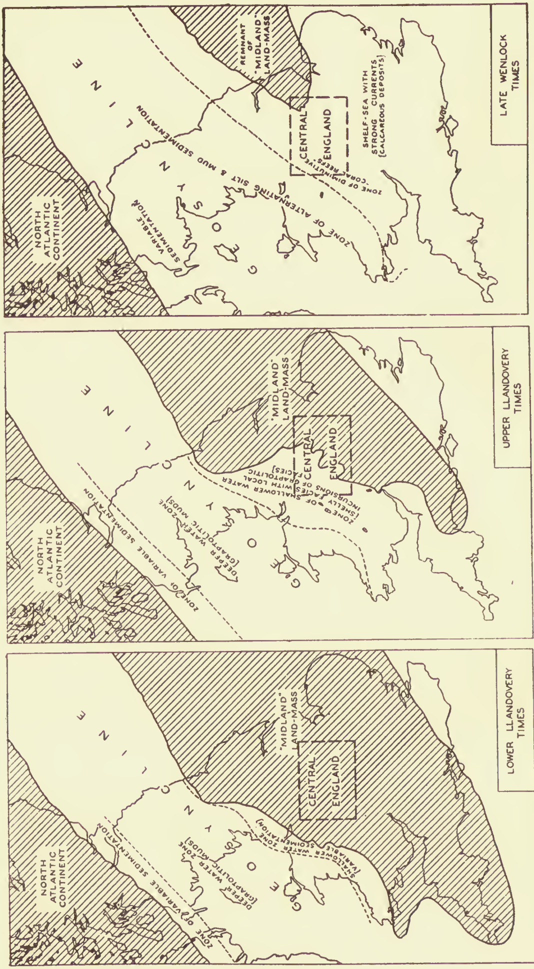


FIG. 3.—*Palaeogeographical sketch-maps illustrating hypothetical stages in the progressive swamping of the 'Midland Land Mass' by the sea in Silurian times*

(*A.6533*)

A. OUTCROP OF BEACON HILL HORNSTONES, BROOMBRIGGS, CHARNWOOD

(*A.2899*)

B. COLUMNAR BASALT, DOSELEY, SALOP.

[*To face page* 16

SILURIAN FOSSILS

1. *Gissocrinus luculentus* Ramsbottom—Wenlock Limestone. **2.** *Bumastus barriensis* Murchison —Barr Limestone. **3.** *Calymene blumenbachi* Auctt.—Wenlock Limestone. **4.** *Stricklandia* cf. *lirata* (J. de C. Sowerby)—Upper Llandovery. **5.** *Acervularia ananas* (Linnaeus), var. *singularis* Lang and S. Smith—Wenlock Limestone. **6.** *Heliolites interstinctus* (Linnaeus), var. *decipiens* McCoy—Wenlock Limestone. **7.** *Poleumita discors* (J. Sowerby), var. *rugosa* (J. Sowerby)—Wenlock Limestone. **8.** *Dawsonoceras annulatum* (J. Sowerby)—Barr Limestone.

[*To face page* 17

and also in South Staffordshire, where they constitute the greater part of the pre-Carboniferous floor of the Coal Measures.

In general, the Silurian rocks in South Staffordshire form the eastern part of a gentle syncline and have a N.E.–S.W., or Caledonian, trend (*see* p. 24). The flank of this fold is exposed in an inlier to the east of Walsall where beds of the Wenlock Series dip at a low angle to the north-west. Beds of the same age have been proved in a series of bore-holes between Walsall and Rowley along the same line of strike. The general synclinal structure is brought out by the distribution of Llandovery rocks, which occur on the periphery of the coalfield. They crop out at Great Barr on the east, at Lickey on the south and apparently rise to near the surface at Stourbridge on the west. In the centre of the coalfield, where the Silurian rocks are at their greatest depth, the Coal Measures rest on Ludlow rocks, while to the west they rest on rocks of the Downton Series.

The effects of movements along Charnoid axes, *i.e.*, having the same direction as the axis of Charnwood Forest, are superimposed on this generally simple arrangement. The Silurian rocks have been buckled by pressure acting mainly in a S.W.–N.E. direction, and as a result the pre-Carboniferous floor is ridged up along a N.W.–S.E. line between the Lickey Hills and Sedgley. Between Dudley and Sedgley the Silurian rocks have been forced up into sharp whale-back folds with N.N.W.–S.S.E. axes, arranged *en echelon*, and now exposed through the denudation of the Coal Measures. These Silurian inliers form the three steep-sided hills known as Dudley Castle Hill, Wren's Nest Hill and Hurst Hill. In each of these Wenlock and Ludlow Beds are exposed. At Sedgley, Ludlow and Downton rocks are exposed in a pitching syncline which is complementary to the Hurst Hill fold. In places the buckling of the Silurian rocks along this line has led to the development of fractures; the elongated folds between Dudley and Sedgley are cut by axial faults; while between Rowley and the Lickey Hills there is an important N.W.–S.E. line of faulting at the south-eastern extremity of which Silurian rocks are again exposed. Ludlow and Downton rocks are exposed at Lye and Netherton in small faulted anticlines trending N.N.E.–S.S.W.

LLANDOVERY SERIES

Beds of Upper Llandovery age form small faulted inliers at Rubery (in the norther part of the Lickey Hills), and at Great Barr on the line of the eastern boundary fault of the coalfield. They have been recorded below Wenlock beds in a recent bore at Walsall.

At Rubery the new Bristol road cuts through nearly the whole sequence of Upper Llandovery beds. Wills has described these beds and divided them into a lower division—the Rubery Sandstone—and an upper division—the Rubery Shales.

The fauna consists of numerous brachiopods, including *Stricklandia lirata*, *Stropheodonta* (*Leptostrophia*) *compressa*, *Coelospira hemisphaerica*, *Atrypa reticularis*, *Camarotoechia sp.*, and *Delthyris elevata*; trilobites, *Encrinurus punctatus* and *Phacops elliptifrons* and corals of Streptelasmid type. The shales have yielded the graptolites *Monograptus marri* and *M. nudus*.

At Great Barr the Upper Llandovery Series is represented by fine-grained yellow sandstones with shaly partings and occasional calcareous bands which are locally rich in fossils such as *Stricklandia lirata* and *Encrinurus punctatus*. The beds are exposed at the side of the Birmingham road, near Shustoke Farm.

An abundance of pebbles of Llandovery sandstone in Midland breccias and conglomerates of Upper Coal Measures and Triassic age, indicates that Llandovery beds cropped out over a wide area during these periods.

Wenlock Series

Barr Limestone.—The Barr Limestone, which is equivalent to the Woolhope Limestone of the Welsh Borders, forms the base of the Wenlock Series. It lies below the Wenlock Shales north of Great Barr forming a narrow outcrop about one and a half miles long now marked by numerous disused quarries. The outcrop is terminated along the strike by the eastern boundary fault of the South Staffordshire Coalfield.

The subdivision is about 30 ft. thick. A very fossiliferous development of the limestone was formerly exposed in a quarry near Hay Head farm, but no good exposures exist at the present time. The trilobite *Bumastus barriensis* is perhaps the most characteristic fossil. The fauna also includes corals such as *Heliolites interstinctus*; numerous brachiopods, *Atrypa reticularis, Howellella crispa, Plectodonta transversalis*, var. *lata, P. duvalii*; occasional gastropods, *e.g., Poleumita globosa*; and the cephalopod *Dawsonoceras annulatum*.

The Barr Limestone has been proved in a deep bore at Walsall, and in a shaft at the Heath Pits, West Bromwich.

Wenlock Shales.—The Wenlock Shales consist of a series of grey-green shales with thin limestone bands. All the outcrops in the district occur

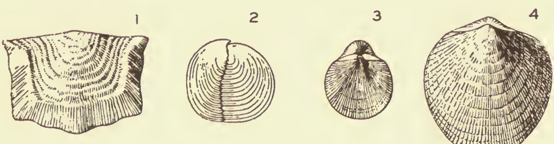


FIG. 4.—*Silurian Fossils*

1. *Leptaena rhomboidalis* (Wilckens). 2. *Rhynchonella* (*Sphaerirhynchia*) *wilsoni* (J. Sowerby) (side view). 3. *Orthis* (*Parmorthis*) *elegantula* Dalman. 4. *Atrypa reticularis* (Linnaeus). All natural size.

within the South Staffordshire Coalfield. Fossils are frequently abundant and include trilobites, *Dalmanites caudatus* and *Encrinurus punctatus*; corals, *Favosites gothlandicus, Heliolites interstinctus* and '*Omphyma*' *subturbinata*; brachiopods, *Sieberella galeata, Atrypa reticularis, Plectodonta transversalis, Leptaena rhomboidalis, Strophonella euglypha, Rhipidomella hybrida, Sphaerirhynchia davidsoni, Meristina obtusa, Dinobolus davidsoni*, and *Delthyris elevata*; lamellibranchs, particularly species of *Orthonota* and *Byssonychia*; and gastropods, *e.g.*, *Platyceras cornutum*. Graptolites have been recorded (*e.g. Monograptus priodon*) from the Walsall and Mucklow Hill bores. Representative Silurian fossils are shown in Plate III and in Fig. 4.

The upper part of the shales is well exposed in the railway cutting at Daw End near Walsall.

Wenlock or Dudley Limestone.—The Wenlock Limestone of Staffordshire consists of two limestone bands separated by nodular beds. The whole group is locally known as the Dudley Limestone. It crops out along the north-western border of the Walsall inlier where it dips at a low angle, and is slightly disturbed by faults. The limestone is also brought to the surface in the three denuded and faulted folds of Wren's Nest Hill, Dudley Castle Hill and Hurst Hill (Sedgley). The Dudley Limestone has been proved below the Coal Measures in collieries of the Oldbury district, as, for example, in shafts at Balls Hill, Hateley Heath and Titford Bridge, in the gate-roads of the Sandwell Park Colliery and in the Knowle and Pennant Hill Collieries. These latter occurrences lie along an approximately N.E.–S.W. line.

The thicknesses of the three subdivisions of the Wenlock Limestone in the Dudley and Walsall districts are as follows: Upper Limestone, 12 ft. to 33 ft., Nodular Group, 90 ft. to 122 ft., Lower Limestone, 33 ft. to 42 ft.

In the Walsall district the Upper Limestone crops out only at the extreme northern end of the inlier, in the neighbourhood of Radley Park. The Upper Limestone of Dudley is not well seen; it is exposed in two small quarries at Shavers End.

The occurrence of lenses or hemispherical masses of unstratified greenish limestone in the midst of the bedded limestones and shales is one of the most remarkable features of the Wenlock Limestone. These go by various local names. In Staffordshire they are known to quarrymen as 'crog-balls' or 'self-lumps'; in Shropshire, where they attain a larger size, they are generally termed 'ballstones.' They are reef-limestones consisting largely of the skeletons of reef-forming organisms, often in the position of growth, and set in a compact matrix of calcareous mud. They vary in size from balls 5 ft. or 6 ft. high and little more in thickness, to masses 50 ft. across and upwards of 20 ft. thick.

Crog-balls are thought to have existed as mound-like structures on the floor of the sea, and to have been formed by the prolific growth, at certain centres, of organisms with calcareous skeletons. They were, in fact, diminutive coral-reefs. The reef-masses are commonest in the Lower Limestone and Nodular Beds, but an isolated example is known in the Upper Limestone at Dudley, while small examples have been recorded in the upper part of the Wenlock Shales near Walsall. Three crog-balls in the basement beds of the Lower Limestone are well exposed in the Daw End Railway cutting; the top of the largest one projects into the overlying Lower Limestone.

The Wenlock Limestone contains a remarkably rich and varied suite of fossils. Dudley has long been famous for the beautifully preserved fossils which were obtained when the limestone was quarried. Some fossiliferous exposures are still accessible at Wren's Nest Hill.

The fauna of the Wenlock Limestone of Staffordshire differs from that of the Welsh Border development in having a greater abundance of trilobites, polyzoa and well-preserved crinoids.

The commonest Dudley trilobite, *Calymene blumenbachi*, popularly known as the ' Dudley Locust,' in the past attracted sufficient attention to become a local emblem. Other fossils include the trilobites *Acaste* [*Phacops*] *downingiae*, *Dalmanites vulgaris*, *Otarion* [*Cyphaspis*] *megalops*, *Acidaspis coronata*, *Homalonotus delphinocephalus* and *Encrinurus variolaris*; the brachiopods *Leptaena rhomboidalis*, *Strophonella euglypha*, *Delthyris elevata*, *Parmorthis elegantula*, *Rhynchotreta cuneata*, *Cyrtia exporrecta* and *Eospirifer radiatus*; corals, *Favosites gothlandicus*, *Heliolites interstinctus*, *Thecia swindernana*, *Halysites catenulata* (' chain coral '), *Acervularia ananas*, *Spongophylloides grayi*, ' *Omphyma* ' *subturbinata*, *Xylodes* [*Cyathophyllum*] *articulatus*, *Coenites repens*, *C. intertextus*, and *Goniophyllum fletcheri*; stromatoporoids, *Labechia conferta* and *Stromatopora concentrica*; gastropods *Poleumita discors*, species of *Platyceras*, *Loxonema* and *Lophospira*; a few lamellibranchs, *e.g. Pterinea retroflexa*; and polyzoa, including species of *Monotrypa*, *Fistulipora*, *Fenestella* and curious pearl-bearing species of *Favositella*.

The crinoids (or ' stone lilies ') of the Dudley Limestone include such forms as *Gissocrinus arthriticus*, *Crotalocrinus rugosus* and *Eucalyptocrinus decorus*. Extensive collections of Wenlock Limestone crinoids are exhibited in the Dudley Museum and in the Museum of the Geological Department of Birmingham University.

Ludlow Series

In the South Staffordshire Coalfield, Ludlow Beds appear in the Silurian inliers of Dudley, Sedgley, Saltwells, Turner's Hill and Walsall; in the Coalbrookdale Coalfield at Linley, Willey and Barrow, and to the west of the Forest of Wyre at Neen Sollars. They have been proved to underlie the Coal Measures in the Tipton–Oldbury area and also near Bridgnorth.

Lower Ludlow Shales.—These consist of grey, buff-weathering shales, and sandy mudstones, with thin impersistent limestones and calcareous nodules. They are similar in character to the Wenlock Shales, and both are referred to locally as ' bavin measures,' bavin being a local name for thin impersistent limestones and calcareous nodules.

The shales are richly fossiliferous. The more characteristic fossils include trilobites, *e.g. Dalmanites nexilis*; cephalopods, *e.g. Gomphoceras ellipticum*; lamellibranchs, *e.g. Cardiola striata* and species of *Slava*, *Goniophora* and *Orthonota*; and the leaf-like polyzoan *Ptilodictya lanceolata*. Graptolites are rare.

Lower Ludlow Shales crop out around Dudley Castle Hill, Wren's Nest Hill, to the north and east of Sedgley, and farther south at Lye and Wollescote and to the west of the Wyre Forest at Neen Sollars. The most fossiliferous locality was formerly near Park Hall, to the north-west of Wren's Nest Hill.

Aymestry Group.—There are several outcrops of this division in the Coalbrookdale Coalfield; in the valley of the Dean Brook; along an anticlinal axis at Willey and the Dean; and again near Barrow. The Aymestry

Limestone also crops out at Neen Sollars. A calcareous development at the top of the Lower Ludlow Shales in South Staffordshire, and known locally as the Sedgley Limestone, is equivalent to the Aymestry Group of Shropshire.

In the Linley area the Aymestry Group is 80 to 100 ft. thick and consists mainly of mottled purple and green calcareous mudstones. The beds here yield a typical Aymestry fauna including *Wilsonia wilsoni*, a large form of *Atrypa reticularis*, *Strophonella euglypha*, ' *Cyathophyllum* ' cf. *augustatum*, *Favosites gothlandicus* forma *forbesi*, *Stropheodonta* (*Leptostrophia*) *filosa* and *Sieberella sp*. The upper part of these beds yields *Dayia navicula* and may be taken as representing the Mocktree Shales of the Ludlow district.

The Sedgley Limestone constitutes the northern rim of the shallow Sedgley syncline, and crops out to the north of Sedgley, where it forms a bold escarpment, and on the east the high ground of Sedgley Beacon. The limestone also crops out in the core of the syncline at Sedgley itself, while farther north at Park Hill it forms part of a small faulted dome. There are small outcrops at Turner's Hill, and at the Hayes near Lye the beds form part of the Netherton anticline. The brachiopod *Pentamerus knighti* has been found in the limestone at Park Hill.

Upper Ludlow Beds.—The Upper Ludlow Beds, poorly exposed in this district, consist of sandy calcareous flags with limestone nodules. They crop out at Sedgley, and at Turner's Hill, the Hayes and Saltwells. In this area they attain a thickness of 40 to 68 ft. Upper Ludlow beds appear in the Coalbrookdale inliers, and also at Neen Sollars; in these localities they are approximately 100 ft. thick.

The fossils of the Upper Ludlow include the problematical *Serpulites longissimus*; the brachiopods *Camarotoechia nucula*, *Chonetes striatellus*, and *Orbiculoidea rugata*; the cephalopod *Orthoceras bullatum*; and the lamellibranchs *Orthonota amygdalina* and *Pterinea* cf. *retroflexa*.

The Silurian limestones of Sedgley, Dudley, Walsall and Barr have been worked for many centuries for lime and as a flux for ironstone. At Dudley the two beds of purer limestone within the Wenlock Limestone were extensively quarried for this use. Where the beds dip steeply, as on the east side of Wren's Nest Hill, the extraction of the limestone has left a pair of moat-like hollows bounded by steeply-dipping walls of shale. Where the dip is lower, pillars of limestone were left to support the overlying beds. In this way resulted pillared caverns, as for example, the ' Daylight ' or ' Lower Limestone ' Caverns near Wren's Nest Farm. Owing to the collapse of the old underground workings, ' sinks ' or ' crownings in ' are of common occurrence in the Dudley district.

The Wenlock Limestone near Walsall has similarly been worked as a flux for the iron-smelters. The flaggy Upper Limestone is said to be particularly suitable in this respect.

In recent years the Lower Limestone at Linley has been worked for the manufacture of cement.

V. DOWNTON SERIES AND DEVONIAN SYSTEM

THE final stages of the Silurian cycle of sedimentation were affected by mountain-building movements which raised much of the British area into a new land-mass, and which gave rise to folds with a general S.W.–N.E. (Caledonian) trend. Central England was not involved in the folding until the middle of the Devonian period, but the movements nevertheless had, from Upper Silurian times onwards, an important effect on sedimentation in this region. For, on account of its proximity to the growing land-mass, there was not only a shallowing and restriction of the sea in that area, but also a great influx of sediment, with the result that the sea became silted up, and the deposits gradually assumed a 'continental' or 'Old Red Sandstone' facies.

The Lower Ludlow Shales and Aymestry Group, consisting of greenish-grey muds and organic limestones, contain, as shown above, a marine fauna consisting of trilobites, echinoderms, corals, brachiopods, mollusca and polyzoa (*see* p. 20). Signs of changes in conditions occur in the greenish-brown Upper Ludlow rocks, which show an increase in sandy detritus and an impoverished marine fauna. The Upper Ludlow marks a shallowing of the sea together with an acceleration of erosion due to uplift of the neighbouring land.

The Downton Series may be taken as transitional between the marine Silurian and the continental Old Red Sandstone, and there are differences of opinion as to whether the Downton beds should be included in the Silurian System or in the Devonian.

The lower part of the Downton deposits, the 'Temeside Group,' would seem to have been laid down in the shallows of the sea. Primitive fishes, mainly ostracoderms, eurypterids, horny brachiopods and a few marine mollusca occur in these beds; but corals, trilobites, graptolites, echinoderms, polyzoa and articulate brachiopods have not been found.

The upper part, the 'Ledbury Group' rocks, indicates more continental conditions, and more closely resembles rocks of Lower Old Red Sandstone age. The deposits of both Ledbury beds and Lower Old Red Sandstone consist of red, purple and green marls and sandstones, with concretionary limestones and pellet-rocks at certain levels. Whilst the Downton rocks consist chiefly of marl, the Old Red Sandstone is mainly sandy. These deposits were laid down in a gulf which may be regarded as a relic of the former Silurian sea. It was bordered on the north-west by mountains with a N.E.–S.W. grain, formed of older rocks newly folded and compacted by earth-movements. This upland, known to geologists as 'St. George's Land,' formed the main source of supply of the sediments which constitute the 'Old Red Sandstone.' The detritus, consisting of highly ferruginous muds and sands, was carried by rivers into the gulf, where it accumulated as deltas. The great thickness of the deposits indicates continuous subsidence. These general conditions are illustrated in the block-diagram, Fig. 5.

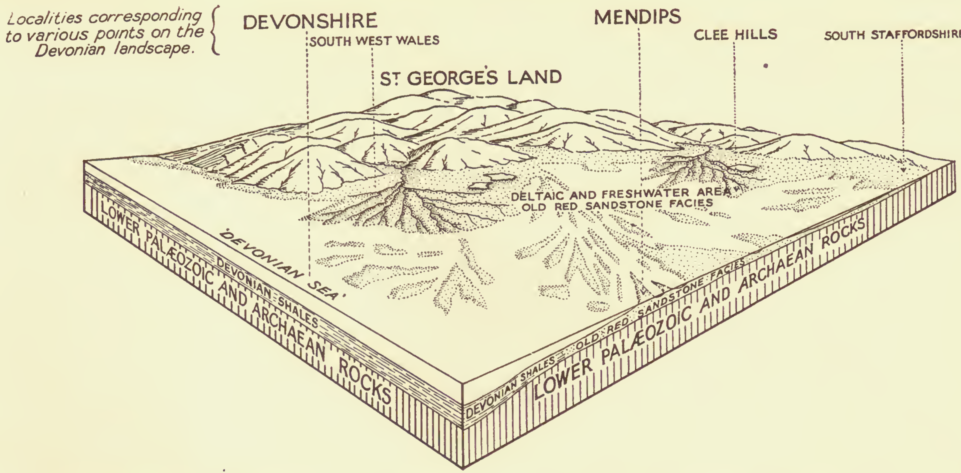


FIG. 5.—*Block-diagram to illustrate the conditions under which the lower part of the 'Old Red Sandstone' is thought to have been accumulated*

To the south of this Anglo-Welsh gulf a second geosyncline came into existence during the deposition of the Downtonian rocks; it was in this southern region that the marine Devonian deposits were laid down. Although there is no evidence of a land-barrier between the two provinces, since the marine and the ' Old Red ' facies are both represented in North Devon, the Anglo-Welsh gulf appears to have been separated eventually from the sea by deltas and sand banks.

By Lower Old Red Sandstone times the gulf had lost its marine character. The region had become one of extensive deltaic flats, perhaps of the coastal salt-marsh type; floods brought sands into the area. The interbedded marls may represent dust arrested on the wet surface of the deltaic flats, while the concretionary limestones which occur at intervals, indicate periods of aridity during which sheets of hard water, left by the floods, were evaporated. Succeeding floods frequently led to the break-up of these calcareous deposits, thus giving rise to pellet-rocks and limestone breccias.

Ostracoderms are the chief fossils found in the Lower Old Red Sandstone, and are mainly associated with cornstones and pellet-rocks.

The deposition of the Lower Old Red Sandstone was followed by folding along N.E.–S.W. axes—the only direct manifestation of Caledonian mountain-building in the south-west Midlands. It is probable that much of the strong folding along Caledonian axes in the Central Midlands is to be attributed to this period. These movements were followed by a long terrestrial period during which the folded and uplifted rocks were eroded. The Upper Old Red Sandstone was consequently laid down under new physiographic conditions. These later Old Red Sandstone deposits were, for the most part, of fluviatile origin, and are characterized by a new fish-fauna.

The oldest known land plants in this country occur in the Old Red Sandstone, and appear to have been relatively abundant in the Midlands during Upper Old Red Sandstone times.

The Upper Old Red Sandstone period ended with a marine transgression which is taken as marking the beginning of Carboniferous times.

W. Wickham King, to whom our detailed knowledge of the rocks is in large measure due, has proposed numerous subdivisions of the Downton and Old Red Sandstone rocks in the West Midlands.

Downton Series

Downtonian beds crop out in Corvedale to the east of Wenlock Edge; farther south the outcrop swings round to the east, through Ludlow, Tenbury and Neen Sollars, and extends down the western margin of the Malvern Hills. Northwards the outcrop skirts the southern margin of the Coalbrookdale Coalfield; the beds, overlain by Coal Measures, are also exposed in the valley of the Dean Brook and probably underlie Coal Measures south-east of Bridgnorth; they appear at the surface again in the Trimpley and Heightington inliers, at the northern end of the Malvern-Abberley line of uplift. The beds are folded and considerably faulted in the two latter inliers.

Downton beds form the sub-Coal Measures floor in the north-western and south-western parts of the South Staffordshire Coalfield, and are exposed locally. Salt water is usually encountered in Downtonian rocks underlying the Coal Measures.

In the West Midlands the Downton Series is about 2,000 ft. thick, and is separable into a lower or Grey division and an upper or Red division. The Grey Downtonian consists mainly of greenish-grey micaceous shales and buff sandstones; the Red Downtonian is chiefly composed of red, purple and green marls or mudstones, with green and purple sandstones and occasional concretionary limestones.

Fish-beds occur at intervals throughout. The characteristic ostracoderm of the Downton Series is *Hemicyclaspis murchisonii.*

Ludlow Bone-Bed.—The Ludlow Bone-bed is a thin calcareous grit, often full of carbonaceous matter, together with the hard dermal studs of the primitive fish *Thelodus parvidens*, fin spines of *Onchus striatus*, ostracods of the genus *Beyrichia*, fragmentary eurypterids, and occasional brachiopods *e.g. Chonetes*, *Orbiculoidea* and *Lingula*. It represents a time of extreme shallowing of the sea.

Temeside Beds.—The Ludlow Bone-bed is immediately succeeded by the Downton Castle Sandstone, which consists of buff sandstones with sandy mudstones and thin calcareous bands. The Temeside Beds are green and purple rubbly shales, with thin sandstones and bone-beds.

The Temeside Beds are well exposed in the valley of the Linley Brook, south-east of Broseley, and again at Netherton in South Staffs.

Their fauna includes horny brachiopods, *Lingula minima*, *Lingula lewisi* and *Lingula cornea*, lamellibranchs *Modiolopsis complanata*, *Ledopsis barroisi*, *Grammysia triangulata*; ostracods, *e.g. Beyrichia kloedeni*; gastropods, *e.g. Holopella sp.*, fragmentary eurypterids, *e.g. Pterygotus*; and fish remains, particularly spines of *Onchus*. The problematical spherical bodies known as *Pachytheca* are common in the Temeside Group. *Lingula minima* is characteristic of the Downton Castle Sandstone, and *Lingula cornea* of the Temeside Shales and higher Downton rocks.

Ledbury or Red Downtonian Group.—The succeeding purple mudstones were included by Murchison in the Old Red Sandstone. The lowest beds are known as the Ledbury Passage Beds. Their outcrop covers most of the ground immediately south of Linley and Shirlett in Shropshire; they crop out in South Staffordshire at Ellowes Park and Saltwells, and have been proved to underlie the Coal Measures in the Baggeridge, Holly Bank and Manor pits. The bank of the stream which forms the northern boundary of Ellowes Park affords one of the best sections of the Ledbury Group in our region. The beds there consist of purple mudstones and green micaceous sandstones.

The Ledbury Group includes two sandstones—the so-called Ledbury fish-zone. The fauna of the whole group includes *Hemicyclaspis murchisonii*, *H. lightbodii*, *Sclerodus pustuliferus*, *Didymaspis grindrodi*, *Climatius ornatus*, *Birkenia sp.*, *Thyestes egertoni*, *Lingula cornea*, *Beyrichia wilckensiana* and *Eurypterus pygmaeus.*

Near Trimpley greenish marls above the Ledbury Group exposed in Man Brook have yielded a large fauna, including *Modiolopsis complanata*, var. *trimpleyensis*, ? *Grammysia anceps*, *Pachytheca*, *Pterygotus*, *Dictyocaris* and fish remains.

The succeeding beds, purple-green sandstones with calcareous bands, interbedded with red marls, are typically developed at Trimpley; bone-beds occur in this group, and have yielded remains of the fishes *Ischnacanthus kingi* and *Didymaspis grindrodi*. These bone-beds comprise the Trimpley fish-zone which is estimated by King to be about 90 ft. thick and some 1,400 ft. above the Ludlow Bone-bed.

The overlying beds, consisting of thin sandstones and marly limestones, interbedded with bright red and green marls, contain the large-shelled ostracod *Leperditia*.

Lower Old Red Sandstone

The Lower Old Red Sandstone is about 800 ft. thick in Shropshire; it consists of sandstones and cornstones with subordinate marls. It is distinguished from the Downton Series lithologically by its higher proportion of sandstones and cornstones, and palaeontologically by the relative abundance of *Pteraspis* and *Cephalaspis*. In a broad sense it has been variously termed the Ditton Series, the Ditton Priors Group and the *Pteraspis* Cornstone Group, but each of these terms has had a slightly different significance. Around Ditton Priors, and at Brown Clee Hill, the Lower Old Red Sandstone forms an elevated plateau.

The basal deposits, occupying a position nearly mid-way between the Ludlow Bone-bed and the Upper Old Red Sandstone, consist of lenticular cornstones and sandstones forming the *Psammosteus* Limestone Group. This belt of rocks is persistent over a wide area and forms a well-marked topographic feature. It forms a convenient lower limit to the Old Red Sandstone, and separating as it does an impermeable group of strata from an overlying more porous group, it is an important horizon from the point of view of water-supply.

The *Psammosteus* Limestone Group is usually about 100 ft. thick and consists of several solid or nodular limestone bands, 4 to 12 ft. thick, with thinner layers of limestone nodules (=' race ') in the lower part. The limestones pass laterally into brownish sandstones with green and red marls. Fossils occur somewhat sparingly in the limestones: they include *Traquairaspis* [*Psammosteus*] *symondsi*, *Ischnacanthus*, and *Corvaspis kingi* and the eurypterid *Eurypterus pygmaeus*. At Leath Bank in Corvedale the lower part of the *Psammosteus* Limestones is represented by sandstone yielding *Pteraspis leathensis*.

The *Psammosteus* Limestones, and the overlying sandstones form well-defined escarpments, for instance, on the south-east side of Corvedale, and on the south-west side of the Teme Velley.

Above these deposits come the Eurypterid Grits, consisting of brown and green sandstones interbedded with green and red marls. They record almost the last appearance of eurypterids in the Anglo-Welsh Gulf. At Trimpley these beds have yielded fossil fish of the genera *Macropetalichthys* and *Onchus*, and also the remains of eurypterids, including *Stylonurus symondsi*, a large spider-like form, and *Pterygotus sp.*, a predaceous type.

In the south-east of the district there next occur bands of brownish sandstone, the *Cephalaspis* Sandstone. At Brown Clee cornstones occur at this horizon.

The remainder of the Lower Old Red Sandstone is made up of red marls, cornstones and false-bedded lenticular sandstones. Fossils are rarer than in the Downton Series, and are mainly confined to the fragmental cornstones. The characteristic forms are *Cephalaspis whitei*, *C. salweyi*, *Pteraspis crouchii* and *P. rostrata*.

Unfossiliferous, false-bedded brown sandstones—Brownstones—crop out on Brown Clee.

Upper Old Red Sandstone

In the Central England region the Upper Old Red Sandstone is known with certainty in the neighbourhood of Titterstone Clee Hill, where it is exposed at Farlow, and at a boring at Whittington Heath, near Lichfield.

The deposition of the Upper Old Red Sandstone was separated from that of the Lower Old Red Sandstone by a long period of earth-movement and erosion, for the deposits rest unconformably on the denuded edges of folds in the Lower Old Red Sandstone and Downton beds. These folds, which have a N.E.–S.W. (Caledonian) trend, are traceable on the south side of Titterstone Clee and at Hope Baggott.

The Farlow Sandstone Group.—The Upper Old Red Sandstone of the Titterstone Clee district belongs to the Farlow Sandstone Group and consists of fine-grained yellow sandstones, and calcareous green and purple sandstones, together with seams of red marl and lenticular quartzose conglomerates. The sandstones are frequently false-bedded. These deposits were laid down on a flood-plain under fluviatile conditions. The prevalence of a desert climate is indicated by certain features of the deposits.

These beds yield a distinctive fish-fauna, which is unlike that of the Lower Old Red Sandstone. The characteristic forms are *Bothriolepis macrocephala*, *Holoptychius giganteus* and *Sauripterus anglicus*. Plant remains occur in sandstone at Stottesdon.

Coarse pebbly red sandstone, not unlike some of the beds in the Farlow Sandstone Group, was proved below the Carboniferous Limestone in a borehole at Gayton (No. 8, Fig. 6).

VI. CARBONIFEROUS SYSTEM

THE CARBONIFEROUS SYSTEM contains two main divisions, the Lower comprising the Carboniferous Limestone Series and the Upper including the Millstone Grit Series and the Coal Measures.

Carboniferous Limestone Series

The beginning of the Carboniferous period was marked by a marine transgression. The core of St. George's Land remained land throughout the period, and with its eastward extension, the Midland Barrier, part of which was occasionally submerged, separated two distinct regions in Lower Carboniferous times. The southern region, the site of the Upper Old Red Sandstone flood-plain (p. 24), was flooded by the sea at the beginning of the Carboniferous period, and there Lower Carboniferous beds lie conformably on the Old Red Sandstone. The region to the north, which had been land throughout Devonian times, was not submerged until a later stage, consequently Carboniferous deposits rest transgressively on Pre-Cambrian and Lower Palaeozoic rocks. The sea probably did not encroach on the Midland Barrier until the middle of the period. In the northern region the Carboniferous Limestone thins out southward against the buried barrier. In North Derbyshire, outside the Central England Region, the formation is more than 1,500 ft. thick; at Breedon in Leicestershire it is 850 ft., at Ellistown 86 ft. and at Stockshouse Farm, near Desford, only 27 ft. (No. 6 on Fig. 6).

The gradual submergence of the northern region seems to have been the result of subsidence connected with warping of the land-mass, a regression of the sea occurring in the south owing to a compensating uplift. As the southern sea retreated, sandy deltas spread out from St. George's Land, so that sandstones were laid down in the south while limestones were being

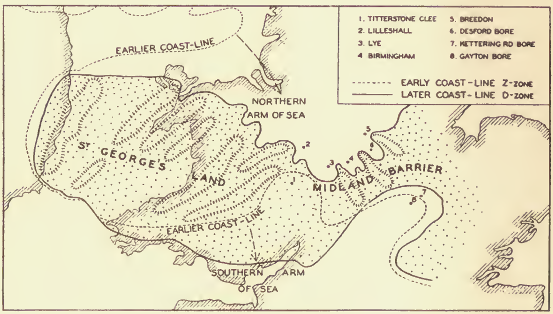


FIG. 6.—*Palaeogeographical sketch-map showing the supposed extent of St. George's Land and the Midland Barrier. This land area is shown stippled, while the outline of present-day land is indicated by oblique ruling*

deposited in the north. These sandstones have long been referred to as ' Millstone Grit,' but while of similar facies to the Upper Carboniferous Millstone Grit they are Lower Carboniferous in age, e.g. Cornbrook Sandstone (p. 30).

Some idea of the possible distribution of land and water during the period is given in Fig. 6. This diagram shows that towards the close of Carboniferous Limestone times the northern shore-line was probably irregular with numerous bays separated by ridges of older rocks. It has been suggested by Boulton that the southern and northern seas were at times connected by straits in the neighbourhood of the site of Leicester.

The Series has been divided into a number of zones, each designated by a letter associated with the name of a characteristic brachiopod or coral genus. These zones, in ascending order K, Z. C, S, and D, have been subdivided into subzones, indicated by figures, thus D_1, D_2, etc. The upper beds have also been subdivided on a facies-faunal basis into the *Beyrichoceras* or B zone and the *Posidonia* or P zone.

In the Midlands, the Carboniferous Limestone Series consists of shallow-water limestones and dolomites, together with shales and sandstones. Grey crystalline limestones of the Lower Carboniferous were deposited in open water, while certain abnormal types known as 'lagoon-phase' deposits (oolites, red polyzoan limestones, calcite mudstones, foraminiferal limestones and dolomites) are believed to have accumulated in restricted shallow tracts of water bordering the land.

There is evidence of contemporary sub-marine volcanic activity, the centres of eruption lying along a belt of instability extending through Shropshire, Staffordshire and Derbyshire.

In the Coalbrookdale Coalfield the Carboniferous Limestone comes to the surface in a narrow faulted outcrop at Lilleshall. The beds rest unconformably on Cambrian sandstone, and are overlain by Coal Measures. The basal beds consist of grey and purple sandstones and grey limestones followed by red-coloured limestones containing the polyzoan *Fenestella*; the red colour is attributed to contemporaneous oxidation in shallow coastal water. Other fossils from these limestones include the brachiopods *Productus garwoodi*, *Avonia* and *Dielasma*, and species of the coral *Zaphrentis*.

In the upper part, nodular limestones, red calcareous sandstones and black shales form the general upward sequence. The nodular limestones yield a rich coral fauna indicative of the D_2 subzone, the chief fossils being the corals *Palaeosmilia murchisoni*, *Dibunophyllum bourtonense* and *Chaetetes septosus*, and the brachiopod *Daviesella* aff. *comoides*. The beds are nearly 300 ft. thick.

Farther south, in the neighbourhood of Little Wenlock, Lower Carboniferous rocks form a narrow outcrop along the western margin of this coalfield. They are also exposed in Lydebrook Dingle and around Doseley.

The lowest bed, the Lydebrook Sandstone, is fine to coarse-grained in texture, and is about 70 ft. thick. It has yielded *Productus* (*Gigantella*) cf. *maximus*, *Dibunophyllum turbinatum*, and lamellibranchs such as *Aviculopecten*, and is referable to the D_2 subzone.

Above this comes a creamy and nodular limestone about 25 ft. thick, followed by a mass of basalt about 100 ft. thick. Overlying the basalt comes a second limestone, about 50 ft. thick, yielding corals such as *Lonsdaleia floriformis* and *Dibunophyllum turbinatum*, and the brachiopod *Productus* (*Gigantella*) *latissimus*. Both these limestones are in the D_2 subzone.

The igneous rock which separates the limestones is a fine prophyritic olivine basalt. R. W. Pocock has shown that it maintains a constant horizon; the absence of contact-alteration in the overlying limestone, the occurrence locally of an overlying bed of red bole formed by contemporaneous weathering, and the slaggy upper surface of the rock, show it to be a lava-flow. In the Doseley quarries, where the basalt is quarried as road-metal, well defined columnar jointing is developed (*see* Plate II B). In some exposures there is a suggestion of pillow-structure. It may be that the lava was erupted along a sub-marine fissure.

The only outcrop of Carboniferous Limestone in North Staffordshire falling within the limits of the present district is at Astbury, south of Congleton, where the limestone is brought up in the core of a small anticline bounded on the west by the Red Rock Fault. In a quarry here the lowest beds exposed are thick-bedded grey limestones, containing the brachiopod *Chonetes papilionaceus*, and various corals. Above come volcanic tuffs and agglomerates which are overlain by shales yielding the cephalopod *Prolecanites* (*Merocanites*) *compressus*, and numerous brachiopods, polyzoa and corals.

Carboniferous Limestone is present under the Coal Measures at Fair Oak Colliery on Cannock Chase, and also north-east of Stafford as proved by a borehole at Chartley. Fragments of Lower Carboniferous rocks occur in the basement-bed of the Coal Measures in the Hilton Main Colliery, near Wolverhampton, and at Wollescote and Lye near Stourbridge; the size of the fragments points to a local derivation. A very thin bed was proved in a trial boring at Whittington Heath, near Lichfield.

In Leicestershire and Derbyshire several small inliers of Carboniferous Limestone occur to the north-east of Ashby-de-la-Zouch. An eastern series along the line of the Breedon Fault comprises the outcrops of Breedon-on-the-Hill, Breedon Cloud, Barrow Hill, Osgathorpe and Grace Dieu; and a western series, those of Ticknall, Calke and Dimminsdale. The western series consists mainly of grey earthy-limestones, which are fairly fossiliferous. The beds are well exposed in quarries at Ticknall. The lower beds include foraminiferal and crinoidal limestones; above these come limestones and shales with a D_2 fauna: *Lithostrotion junceum*, *Dibunophyllum bipartitum*, *Productus* (*Gigantella*) *giganteus* with other species of *Productus*, and *Goniatites crenistria*. The succeeding beds are almost pure dolomites; they are overlain by a shale series.

In the easterly inliers grey and yellow dolomites with but few fossils predominate. The best exposure is the large quarry at Breedon Cloud. The lowest dolomites exposed yield *Productus humerosus*, establishing their C_2 age; these are succeeded by purple-stained dolomites with pebbles and a C_2-S_1 fauna of corals and brachiopods. Later beds yield brachiopods, including *Cyrtina septosa* and corals indicating D_1 age, succeeded again by dolomites with goniatites and brachiopods of B_2 age. The grey and yellow dolomites of Leicestershire may have been formed by contemporaneous dolomitization of calcareous muds in coastal lagoons.

Carboniferous Limestone has been proved in boreholes at Tonge, Ellistown, Stockshouse Farm, near Desford, Castle Donington and Chellaston.

Lower Carboniferous rocks crop out on the northern and southern sides of Titterstone Clee. The Carboniferous Limestone is here conformable with the Farlow Sandstone, and consists of massive grey limestones with some beds of white oolite. These beds are well exposed in quarries at Oreton and Gorstley. The lowest beds are ascribed to the K Zone. The higher beds contain a Z_2 fauna, including *Syringothyris cuspidata*, *Camarotoechia mitcheldeanensis* and species of the corals *Zaphrentis* and *Michelinia*. Fish-remains are common in this zone, and include teeth of *Orodus* and spines of *Ctenacanthus*.

The Z_2 limestones are succeeded by the Cornbrook Sandstone, a thick bed which overlaps on to the Old Red Sandstone. This sandstone has a maximum thickness of 1,000 ft. as in Cornbrook Dingle, and consists of grey, red, yellow and brown sandstones, coarse pebbly grits, and occasional seams of brightly coloured clay. It marks a regression of the sea, and a return to Old Red Sandstone conditions, the result of relative uplift of the land. The coarse detritus was probably brought down by a river from St. George's Land. Within 300 ft. of the base there is a thin layer of clay with limestone nodules in which marine gastropods and sea-lilies have been found, indicating a temporary re-advance of the sea. Plants of Lower Carboniferous type (*e.g. Lepidodendron veltheimianum*) were recorded by Kidston from the sandstone.

In Northamptonshire red and yellow dolomitic limestone and sandstones with D_2 fossils were encountered in a borehole near Kettering Road, Northampton (No. 7, Fig. 6). At Gayton, five miles to the south-west, red and grey shales with early Carboniferous fossils and white limestones were found to rest directly on coarse red sandstones and marls, apparently of Old Red Sandstone type.

MILLSTONE GRIT SERIES

The Lower Carboniferous period was brought to an end by elevation and erosion of the deposits at the margins of the northern sea, with the result that in Central England the lower Upper Carboniferous strata, those of the Millstone Grit Series, rest unconformably on beds of the Carboniferous Limestone Series.

At the beginning of Upper Carboniferous times, rivers draining the mountainous St. George's Land, and also a land-mass to the north and north-west, conveyed great quantities of silt and coarse sediments which were built into deltas in the sea. These deposits comprise the alternating shales and grits of the Millstone Grit Series.

The region of maximum accumulation lay to the north of what is now Central England. A thick development of the Series is present in Lancashire and is composed of material chiefly derived from an old land mass to the north. From there the deposits thin out southwards in the direction of the old Midland Barrier (Fig. 6). Several thick beds of grit characterize the series and all occur at more or less definite horizons. Each perhaps represents a separate period of uplift of the adjacent land-mass, whereby erosion was periodically accelerated, and the amount of detritus reaching the gulf proportionately increased.

These grit beds are made up of lenses of coarse sandstone and conglomerate, and originated under deltaic conditions. The subsidence of the gulf at times failed to keep pace with the deposition of the coarse sediments; the deltas were then built up to water-level, and exposed as sandy flats which became colonized by swamp vegetation. In this way originated the fireclays and thin coals by which some of the grits are capped. The composition of these grits points to the derivation of material from a land-mass largely composed of granite, gneiss and other metamorphic rocks; an abundance of fresh felspar indicates the denudation of the mountainous parts of the continent under desert conditions. Each grit phase was terminated by renewed subsidence, so that grits became buried beneath fine muds.

The Millstone Grit Series shows a rhythmic oscillation between marine and deltaic conditions. The waters in which the bulk of the Millstone Grit shales was accumulated were not favourable to marine life, but during periods of greater submergence marine conditions prevailed, and then goniatites and marine lamellibranchs thrived. The remains of these organisms are found in the ' Marine-bands ' which occur at intervals throughout the Series. Successive marine bands are characterized by different species of goniatite, which provide reliable means of correlation of the strata as a whole, and the Series has been divided into zones on the basis of the goniatite succession. The zones, designated by the initial letters of the generic names of the various goniatites, are in ascending order, E, H, R and G; they are indicated in Fig. 7.

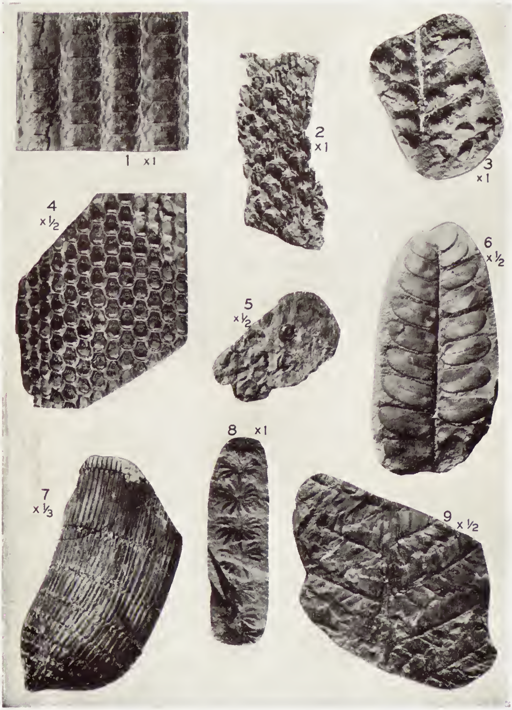
Drifted plant remains are locally abundant in both grits and shales. The Lower Carboniferous flora persists into the lowest beds of the Series, but it is replaced by a flora of Upper Carboniferous type before the end of ' E ' times.

The Millstone Grit Series, well developed in North Staffordshire, is exposed over the elevated country between the low-lying Potteries Coalfield and the limestone uplands of Derbyshire; it also crops out on the northern side of the Leicestershire Coalfield, yielding *Gastrioceras* and *Reticuloceras* at Newbould. Attenuated representatives of the Series have been proved in boreholes in South Derbyshire at Repton where *Eumorphoceras bisulcatum* was collected, and in Leicestershire at Hathern, Ellistown, Osbaston House, near Nailstone, and Stockshouse Farm, near Desford. Millstone Grit was also proved in boreholes near Rugeley, and at Whittington Heath, near Lichfield, but is not known either in the southern part of the South Staffordshire Coalfield or in the Warwickshire Coalfield.

Tracts of moorland country near the junction of Cheshire, Staffordshire and Derbyshire mark the outcrop of the Millstone Grit Series, and over them the relationship of physiography to geological structure is well brought out. The alternating beds of grit and shale, disposed in a series of anticlines and synclines, give rise to lines of terraced hills; the main grits, resistant to weathering, form strong escarpments locally known as ' edges '; for example, Brown Edge, the summit of which is 888 ft. above sea-level, and Badderley Edge with a maximum elevation of 787 ft. Valleys have been carved in the softer shales, which also form the more gently rising ground below the grit escarpments.

On the eastern margin of that part of North Staffordshire which is included in Central England there is a line of anticlinal folding and faulting, followed westwards by a syncline, the Rudyard trough; to the south lies the Cheadle basin. West of the Rudyard trough comes the Biddulph anticline, followed by a complementary syncline, a pitching down-fold which forms the northern part of the Potteries Coalfield. This is bounded by the Red Rock Fault separating the Carboniferous area from the Trias plain of Cheshire. Bold Millstone Grit edges bound these various synclinal areas, all of which are occupied by Coal Measures.

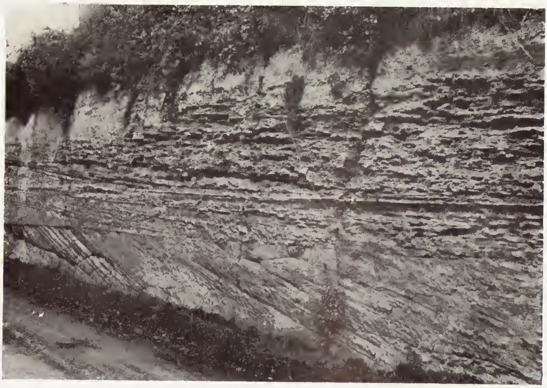
The Millstone Grit succession is diagrammatically shown in Fig. 7, the section being based mainly on that observed in North-West Staffordshire. The lower part of the Series is dominantly a shale facies, and was formerly classed, together with the Lower Carboniferous shales which in places underlie it, as the Pendleside Series. The unconformity which locally divides the Lower Carboniferous rocks from the shales of the Millstone Grit



CHARACTERISTIC FOSSIL PLANT REMAINS FROM THE COAL MEASURES OF THE NORTH STAFFORDSHIRE COALFIELDS

1. Clubmoss bark: *Sigillaria tessellata* Brongniart, forma *nodosa* (Bowman). **2.** Clubmoss bark: *Lepidophloios acerosus* Lindley and Hutton. **3.** Part of seed-fern leaf: *Sphenopteris dilatata* Lindley and Hutton. **4.** Clubmoss bark: *Sigillaria trigona* (Stenberg). **5.** Gymnospermous seeds: *Carpolithus membranaceus* Goeppert. **6.** Part of seed-fern leaf: *Neuropteris gigantea* Sternberg. **7.** Pith cast; stem of horsetail: *Calamites suckowi* Brongniart. **8.** Horsetail leaf: *Annularia microphylla* Sauveur. **9.** Part of seed-fern leaf: *Neuropteris heterophylla* Brongniart.

[*To face page* 32



(*A. 2057*)

A. LOWER MOTTLED SANDSTONE, SHOWING CURRENT-BEDDING; ROCK HALL, PRESTON BROCKHURST, SALOP

(*A.6542*)

B. TRIASSIC DEPOSITS UNCONFORMABLY FILLING VALLEY IN PRE-CAMBRIAN ROCKS, CHARNWOOD, LEICESTERSHIRE

[*To face page* 33

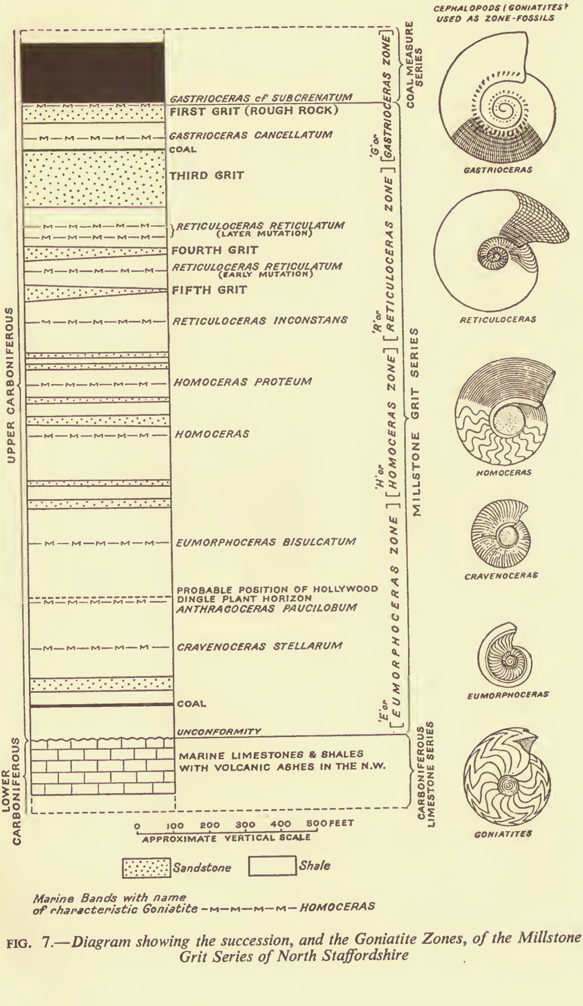


FIG. 7.—*Diagram showing the succession, and the Goniatite Zones, of the Millstone Grit Series of North Staffordshire*

Series is not always apparent when the former are shaly in facies, but the boundary between the two is marked by the incoming of the goniatite *Eumorphoceras*.

The lower part, belonging to the E and H Zones, consists of dark shales with occasional marls and fire-clays, together with frequent beds of quartzite known as ' crowstones,' very hard close-grained sandstones cemented by secondary silica.

Interesting plant-beds occur, such as that in the shales exposed in Dingle Brook, which is the lowest horizon at which representatives of the Upper Carboniferous flora are known. S. W. Hester has shown that this plant-bed falls within the E Zone.

The upper part of the Series, characterized by massive grits, belongs to the R and H Zones. The grits have long been numbered according to the order in which they are encountered in shaft sinkings, the uppermost being the First Grit. The terms First, Second, Third and Fourth Grit have been applied in different areas to grits of various ages, and consequently, as a rule, have no precise value in correlation. For example, the Second Grit of Lancashire is not present in North Staffordshire; the Fourth (or Kinderscout) Grit of Derbyshire is represented by two distinct grits in the north-eastern part of Staffordshire known as the Fourth and Fifth Grits; these die out to the south and west. The Fourth Grit is unknown south of Cheddleton or west of Biddulph Moor, while the Fifth is of still more limited extent. The First and the Third Grits of North Staffordshire are the most persistent; the First Grit is probably the only important grit which extends into Leicestershire.

The grits and crowstones of the Millstone Grit Series are quarried for road metal, and some of the grits have long been famous as grindstones. In recent years they have been used to a considerable extent in paper mills.

Although the shales of the series are actually of greater thickness than the grits, they are poorly exposed and their outcrops are commonly obscured by downwash from the overlying grit escarpments.

VII. CARBONIFEROUS SYSTEM (*continued*)

Coal Measures

THE COAL MEASURES of Central England comprise a lower group of strata, the Lower and Middle Coal Measures, which consist mainly of grey shales with coal seams, and an upper group, the Upper Coal Measures, in which red marls and sandstones predominate. The terms, ' Lower,' ' Middle ' and ' Upper ' have in the past, however, been employed in different senses in different areas; consequently an attempt has been made in recent years to classify Coal Measures strata on the evidence afforded by fossil plants and animals. The various classifications are shown in Fig. 8. For general purposes, it is convenient to refer to the grey measures with coals as the ' Productive Measures,' and the overlying, mainly unproductive, beds as the ' Barren Measures.'

PRODUCTIVE COAL MEASURES

The Productive Coal Measures represent a continuation of the deltaic conditions initiated in Millstone Grit times (*see* p. 31). Throughout the period of their deposition mud deltas occupied the great estuary which lay to north of the Midland Barrier. These deltas were sometimes covered by tracts of fresh or brackish water, and sometimes by forested swamps in which accumulated the peats that ultimately formed the coal seams. The surface of the delta was never much above sea-level, and at intervals the sea invaded the area, but these marine phases were of short duration. The resulting marine deposits, though thin, are of importance in the correlation of coal seams as encountered in the various collieries, and as traced from place to place. (*See* Fig. 9.)

Although the Coal Measures are of shallow-water and terrestrial origin, a great thickness was accumulated, their deposition being accompanied by long-continued subsidence of the pre-Carboniferous floor. During the accumulation of the Productive Measures the region of maximum subsidence lay to the north of Central England. As subsidence continued the area of deposition became larger and deltas spread farther and farther south, ultimately encroaching on the Midland Barrier. The beds were thus deposited on a surface which sloped up to the south, and the lowest Coal Measures are, therefore, present only in the north, where they rest conformably on the Millstone Grit Series; the higher beds successively overlap the lower beds southwards, some eventually resting on pre-Carboniferous rocks.

The coast-line of the land on which the Coal Measures deltas encroached was irregular. Promontories and whale-back ridges of older rocks projected above the swamps. To-day the elevations in the sub-Coal Measures floor are termed, in the South Staffordshire Coalfield, ' Silurian banks ' and are causes of the local absence of coal seams.

Variations in the original thickness of the Coal Measures of Central England were partly produced by differential subsidence from place to place; some areas subsided while others remained stable or even showed a tendency to rise. The most deeply-sunk area occupied the northern part of Central England, and was termed by Lapworth the ' Stafford Basin.' In the south its eastern and western limits are practically coincident with the Charnwood and Wrekin hills. Two narrow southerly extensions of this main basin of deposition—the Wyre Sub-basin and the Warwick Sub-basin—were separated from one another by blocks of country which showed a tendency to rise.

Differential sinking of the Coal Measures deltas is perhaps best illustrated by the local formation of thick coal seams which, when traced into adjacent areas, are found to split into thinner seams separated by other sediments. On the northern edge of the block separating the Wyre and Warwick Sub-basins, a minimum amount of subsidence took place, and peat-formation continued over long periods. The Thick Coal of the Dudley district has a maximum thickness of 30 ft. The seam is made up of a number of distinct layers, and when it is traced northwards these layers are found to become separated by a gradually increasing thickness of sediments, until at Littleton the aggregate thickness of deposit corresponding to the 30-ft. seam at Dudley, is 170 ft. In the Dudley area of the Thick Coal there was slow

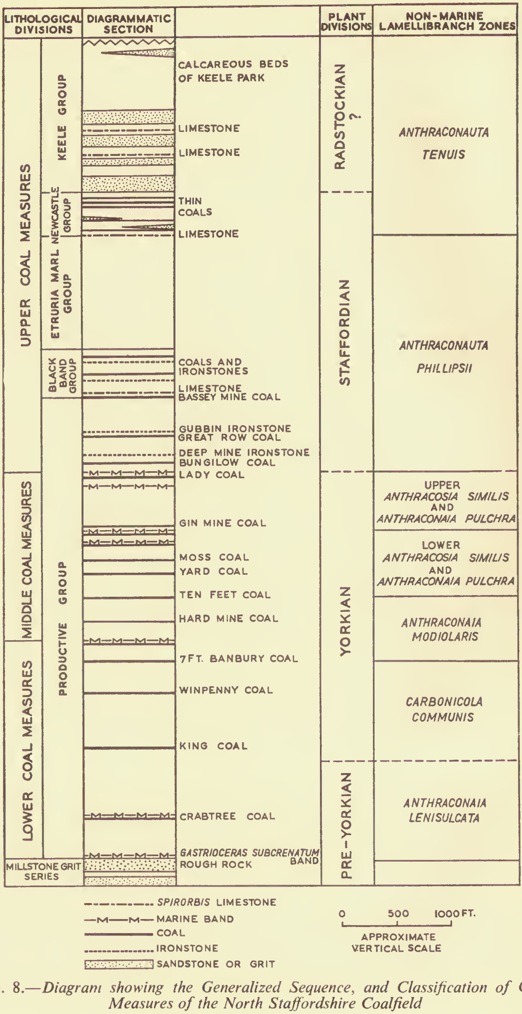


FIG. 8.—*Diagram showing the Generalized Sequence, and Classification of Coal Measures of the North Staffordshire Coalfield*

sinking for a considerable period during which peat-growth was uninterrupted by submergence of the forest. Farther north subsidence was more rapid and intermittent; the forest was drowned from time to time and peat-formation replaced by the deposition of deltaic muds until the surface of the delta was built up to water-level and the forest could grow again. As far as is known, the coal seams thin out southward and finally fail altogether. The associated seat-earths predominate over all other types of sediment and give rise to-day to the important fireclay industry of the Stourbridge area. The origin of split coal seams, and the split seams of the South Staffordshire Coalfield, are shown in Fig. 9, A and B.

Coal-forming peats accumulated on coastal swamps which supported a wide range of plants, from herbs to forest-trees; the Coal Measures yielding a great number and variety of plant remains. The chief groups were club-mosses (Lycopods), horsetails (*i.e.* Equisetales, the stems of which are known as *Calamites*), and seed-ferns (plants with fern-like leaves, but bearing seeds, such as *Neuropteris* and *Alethopteris* and belonging to the Gymnosperm group). Many club-mosses (*e.g. Lepidodendron* and *Sigillaria*) were forest trees, some attaining a height of over a hundred feet. Characteristic fossil plants from the Coal Measures of the North Staffordshire Coalfields are shown in Plate IV.

Fossil plants are often abundant in the Coal Measures as impressions in shale and as casts and moulds in sandstone and ironstone. A study of these remains reveals four successive floras by which the strata can be subdivided (*see* Fig. 8). This four-fold subdivision was established by Kidston. Each flora is distinguished mainly by the relative proportion of various plant types, but partly by the occurrence of certain species having a restricted range. The earliest flora, that of the pre-Yorkian Beds, occurs in the upper part of the Millstone Grit Series and the lowest Coal Measures, typical plants being *Neuropteris schlehani* and *Sphenopteris hoeninghausi*; *Sigillaria* and *Lepidodendron* also occur. Most of the plants found in the pre-Yorkian are more abundant in the succeeding Yorkian subdivision, the Middle or Main Productive Measures of the Midlands. This flora, the richest in plant remains, is characterized by the abundance of *Sigillaria*, particularly *S. scutella*, *S. rugosa* and *S. tessellata*, and also of *Neuropteris gigantea*, *N. heterophylla*, *Alethopteris lonchitica* and *Lepidodendron obovatum*. The Staffordian flora is found in the top of the main Productive Group and persists through the lower divisions of the Upper Coal Measures, characteristic forms including *Linopteris münsteri* and *L. obliqua*. Many species found in the Yorkian also occur. The fourth or uppermost flora, the Radstockian, is poorly represented in Central England. Typical plants in Red Measures, of supposed Radstockian age, are *Asterotheca cyathea* and *Neuropteris scheuchzeri*, and species of *Pecopteris* and *Odontopteris*.

In the tracts of fresh or estuarine water which bordered the coal swamps, lamellibranchs allied to the modern fresh-water mussel thrived. Their shells occur frequently in the Coal Measures shales and ironstones, usually crowded together in layers to form ' Mussel bands.' These non-marine lamellibranchs (*e.g. Anthraconaia*, *Carbonicola*, etc.) have proved to be of value as zonal indices, and permit of more detailed correlation of the strata than do fossil plants (*see* Fig. 8).

Thin beds containing marine fossils occur in the Lower and the Middle

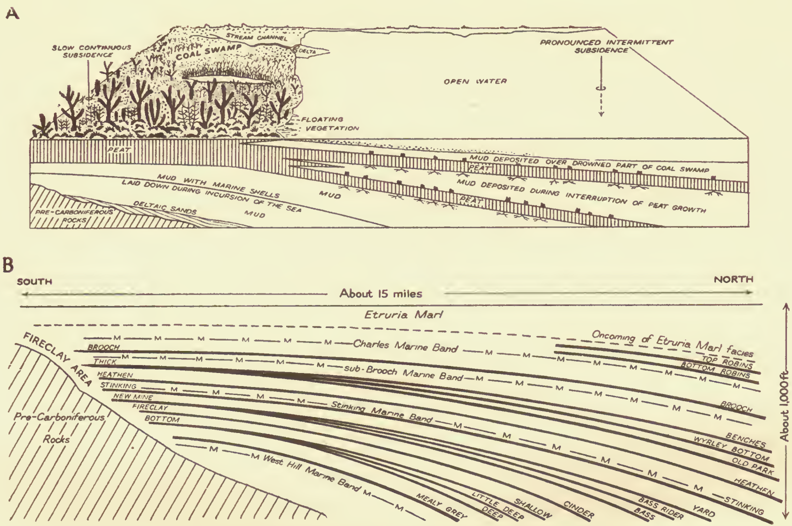


FIG. 9.—A. *Block-diagram illustrating the origin of split Coal Seams (based on L. J. Wills).* B. *Diagrammatic Section showing the northward splitting of coal seams in the South Staffordshire Coalfield, and the correlation of seams on the evidence provided by marine bands. (Based on Jukes, with modifications by G. H. Mitchell and C. J. Stubblefield.)*

Coal Measures; they represent the incursions of the sea already referred to (p. 35). These marine bands commonly yield the shells of goniatites, *e.g.*, *Gastrioceras* and *Anthracoceras* and sometimes of nautiloids, brachiopods *e.g.*, *Lingula* and lamellibranchs *e.g.*, *Dunbarella*. Seven principal marine-bands have been proved in the Potteries Coalfield, two in the Lower and five in the Middle Coal Measures (Fig. 8). The marine band which forms the roof of the Crabtree Coal yields *Gastrioceras listeri*; it is correlated with the Fair Oak Marine Band of the South Staffordshire Coalfield, and with the Bullion Mine Band of Lancashire.

The Coal Measures of the Midlands include several varieties of rock, notably coal, shale, sandstone, ironstone and fireclay. Two main classes of coal are present—humic (or bituminous) and cannel. Humic coal constitutes the main seams, while cannel coal is of local occurrence and of less economic importance.

Although coal seams are the most striking feature of the Productive Coal Measures, they actually comprise only about 2 per cent of the total thickness of the series. Shales, and to a lesser extent sandstones, are the main rock-types.

The shales of the Productive Measures, often termed ' binds,' are mainly grey or black in colour and contain much carbonaceous material. At certain horizons there are layers of bluish shale, greasy to the touch, and locally known as ' soapy binds.'

Sandstones in the Coal Measures are usually impersistent and false-bedded. They represent the coarser detritus conveyed by rivers and deposited as sand banks and local deltas in the lagoons bordering the swamps. Coal seams are occasionally interrupted locally by lens-shaped masses of shale or sandstone known as ' washouts,' which represent the silted-up channels of meandering streams which flowed across the coal swamps, sometimes cutting into the peat and underlying deposits. Since the shrinkage of the peat consequent on its change into coal greatly exceeded the compaction of the silt filling the channel, ' wash-outs ' frequently have a convex upper surface. In the Baremoor Colliery in the South Staffordshire Coalfield, a typical ' wash-out ' in the Thick Coal was revealed many years ago, and another, illustrated in Fig. 10, was encountered at the Victoria Colliery at Hawkesbury, Warwickshire.

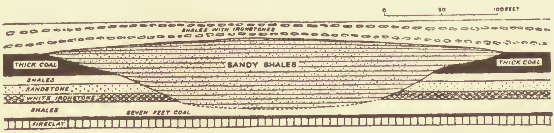


FIG. 10.—*Diagram of ' Wash-out ' in the Thick Coal of Warwickshire: Victoria Colliery, Hawkesbury*

Bands and nodules of clay-ironstone are common in the shales of the Coal Measures. Clay-ironstone is hard and compact, typically bluish in colour but weathering to a rusty brown. It originated through the segregation of iron (ferrous) carbonate formed in muds saturated with iron-rich water and containing decaying vegetation.

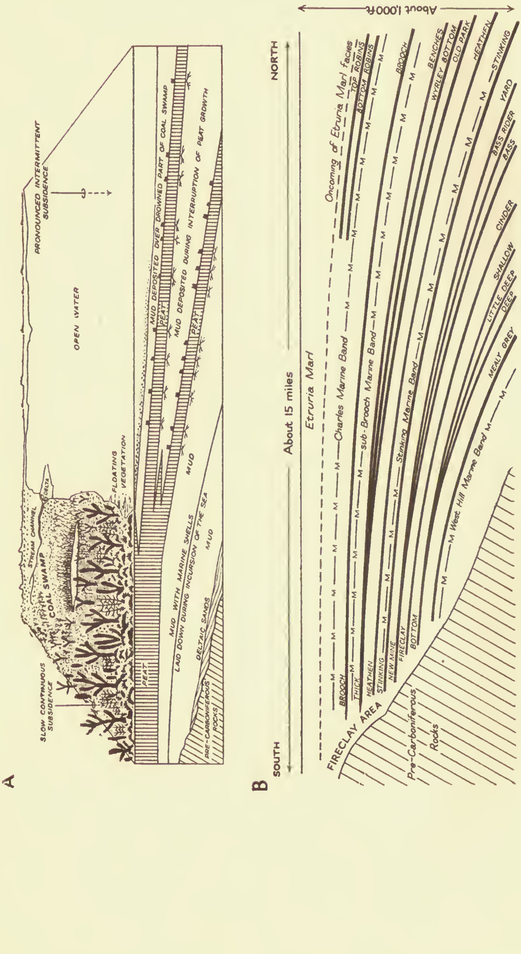


FIG. 9.—A. *Block-diagram illustrating the origin of split Coal Seams (based on L. J. Wills).* B. *Diagrammatic Section showing the northward splitting of coal seams in the South Staffordshire Coalfield, and the correlation of seams on the evidence provided by marine bands. (Based on Jukes, with modifications by G. H. Mitchell and C. J. Stubblefield.)*

Coal Measures; they represent the incursions of the sea already referred to (p. 35). These marine bands commonly yield the shells of goniatites, *e.g.*, *Gastrioceras* and *Anthracoceras* and sometimes of nautiloids, brachiopods *e.g.*, *Lingula* and lamellibranchs *e.g.*, *Dunbarella*. Seven principal marine-bands have been proved in the Potteries Coalfield, two in the Lower and five in the Middle Coal Measures (Fig. 8). The marine band which forms the roof of the Crabtree Coal yields *Gastrioceras listeri*; it is correlated with the Fair Oak Marine Band of the South Staffordshire Coalfield, and with the Bullion Mine Band of Lancashire.

The Coal Measures of the Midlands include several varieties of rock, notably coal, shale, sandstone, ironstone and fireclay. Two main classes of coal are present—humic (or bituminous) and cannel. Humic coal constitutes the main seams, while cannel coal is of local occurrence and of less economic importance.

Although coal seams are the most striking feature of the Productive Coal Measures, they actually comprise only about 2 per cent of the total thickness of the series. Shales, and to a lesser extent sandstones, are the main rock-types.

The shales of the Productive Measures, often termed ' binds,' are mainly grey or black in colour and contain much carbonaceous material. At certain horizons there are layers of bluish shale, greasy to the touch, and locally known as ' soapy binds.'

Sandstones in the Coal Measures are usually impersistent and false-bedded. They represent the coarser detritus conveyed by rivers and deposited as sand banks and local deltas in the lagoons bordering the swamps. Coal seams are occasionally interrupted locally by lens-shaped masses of shale or sandstone known as ' washouts,' which represent the silted-up channels of meandering streams which flowed across the coal swamps, sometimes cutting into the peat and underlying deposits. Since the shrinkage of the peat consequent on its change into coal greatly exceeded the compaction of the silt filling the channel, ' wash-outs ' frequently have a convex upper surface. In the Baremoor Colliery in the South Staffordshire Coalfield, a typical ' wash-out ' in the Thick Coal was revealed many years ago, and another, illustrated in Fig. 10, was encountered at the Victoria Colliery at Hawkesbury, Warwickshire.

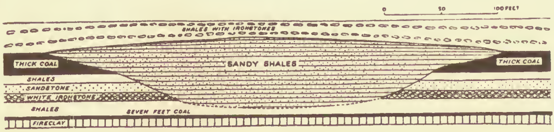


FIG. 10.—*Diagram of ' Wash-out ' in the Thick Coal of Warwickshire: Victoria Colliery, Hawkesbury*

Bands and nodules of clay-ironstone are common in the shales of the Coal Measures. Clay-ironstone is hard and compact, typically bluish in colour but weathering to a rusty brown. It originated through the segregation of iron (ferrous) carbonate formed in muds saturated with iron-rich water and containing decaying vegetation.

Coal seams are commonly underlain by tough claystone known as ' fireclay.' With increase in silica-content fireclays pass into an almost pure silica rock known as ' ganister.' Fireclays and ganister usually contain impressions of plant-rootlets, and indeed represent the actual soils which supported the coal-forming vegetation. Fireclays withstand high temperatures without fusion, and are used in the manufacture of fireproof bricks and furnace ' seggars.'

BARREN OR UPPER COAL MEASURES

As already noted, the Middle Coal Measures of Central England are followed by a relatively barren series of rocks, the Upper Coal Measures.

The red coloration of the higher beds of this series points to the gradual advance of semi-arid conditions in Central England during late Carboniferous times. The complete oxidation of carbonaceous matter and the concentration of iron salts through long exposure above the level of ground water led to the reddening of the sediments. The change in conditions was brought about by crustal movements, by which, during the Upper Coal Measures period, mountain ranges were elevated in regions bordering the areas of deposition of the Midlands. The rising mountains are thought to have converted the former delta-choked estuary into a land-locked basin, and also to have intercepted rain-bearing winds.

It has been remarked previously (p. 36) that subsidence during Carboniferous times was greater in some areas than in others. This difference was accentuated as the ' Hercynian earth-storm ' developed (*see* p. 43), and in places uplift and erosion led to gaps in the succession. For example, in Shropshire, at the edge of the basin of deposition, the sediments were uplifted and eroded at the end of Yorkian times, and in the Coalbrookdale Coalfield the Upper Coal Measures consequently appear to rest with marked unconformity on the Productive Series. It is notable that there was considerable igneous activity during the Yorkian-Staffordian interval (*see* p. 42).

In Middle Coal Measure times the region of maximum depression lay to the north of Central England, but it appears to have been moved farther and farther south by the gradual uprise of the Pennine area; during the deposition of the Upper Coal Measures the basin was centred over the site of North Staffordshire, and in Enville times (p. 48) over Warwickshire The Upper Coal Measures (excluding the Enville Series) reach a maximum thickness in North Staffordshire, where they are estimated to be over 2,500 ft. thick. The various divisions of the series thin out southwards against the ' Midland Barrier ' in an overlapping series.

In Central England Upper Coal Measures are exposed in all but the Cheadle and Leicestershire Coalfields; the succession of deposits in the Potteries Coalfield has been taken as an example. The sub-divisions recognized there are, in ascending order, the Black Band Group, the Etruria Marl Group, the Newcastle Group and the Keele Beds.

The Blackband Ironstone Group.—These are mainly of marls, clay-ironstones and thin limestones with a few coals. The group includes a series of marls known as the Pottery Marls. The ironstones are dark brown laminated clay-ironstones with layers of coaly matter—hence the term 'blackband'—and are usually full of *Stigmaria* casts and shells of *Anthraconauta* [*Anthracomya*] *phillipsii.* Plants from the ironstones include *Linopteris münsteri*, *Calamites suckowi* and *Neuropteris scheuchzeri.* Locally oil-shales occur in association with the ironstones. Two thin limestones occur near the base of the group and yield shells of '*Carbonicola vinti*,' and the coiled tubes of the worm *Spirorbis.*

The Etruria Marl Group.—This group, which consists of purple, red or mottled 'blocky' marls, is recognized in the Warwickshire and South Staffordshire Coalfields, as well as in the Potteries. It is possibly represented in Coalbrookdale by the basal beds of the Coalport Group, and in the Wyre Forest Coalfield by the top of the Sweet Coal Group. It has been suggested that the deep reddish coloration of the marl originated through the derivation of material from the semi-arid weathering products of contemporary lava-flows and older igneous rocks. The beds are in general unfossiliferous, but occasional ironstones yield *Anthraconauta phillipsii*, and a few poorly preserved plant remains have been found in the clays.

Etruria Marl is extensively worked for the manufacture of Staffordshire blue bricks and pipes.

Interbedded with the marls, particularly near the base of the group, are lenticular beds of grit and conglomerate which are included under the general name of 'espleys.' These are usually green or white, often contain pellets of marl, and have either a ferruginous or a calcareous cementing matrix They are thickest and most common in the South Staffordshire Coalfield, but appear to die out northwards. They were probably formed by the attrition of rock-waste transported by floods from escarpments and islands of Cambrian or Archaean rocks. The group as a whole overlaps the Productive Measures.

The Newcastle Group.—This marks a return to the conditions under which the Productive Measures were accumulated, and consists of grey and green shales, with beds of grey sandstone and thin seams of coal. On account of its grey colour, this group contrasts with the red rocks above and below it. In the Potteries plant remains occur at three horizons. The forms recorded include *Asterotheca arborescens*, *Sphenophyllum emarginatum*, *Alethopteris aquilina* and *Neuropteris scheuchzeri.* Two well-marked limestones occur near the base of the group in N. Staffordshire, and have yielded *Anthraconauta calcifera* and ostracods. In Warwickshire and South Staffordshire it is known as the Halesowen Group, and as the Highley or Sulphur Coal Group in the Wyre Forest; in Coalbrookdale it is represented by the greater part of the Coalport Group. The component beds of the Coalport and Halesowen Groups overlap against the Midland barrier and rest with slight unconformity on different older formations.

The Keele Beds.—Present in all Central England Coalfields in which Upper Coal Measures are exposed, these consist mainly of red and purple sandstones and bright red marls and clays. The marls and clays contain several extensive beds of *Spirorbis* limestone—thin beds of compact, almost porcellaneous limestone, sometimes yielding tubes of the worm *Spirorbis* and ostracod shells, but often unfossiliferous. The limestones occur at intervals in the Upper Coal Measures and are generally regarded as peculiar to this series, but one limestone of this type has been met with 230 ft. below the top of the Productive Measures in the Potteries Coalfield. *Spirorbis* limestones vary in colour from black to light grey and weather to a creamy white or buff. They form relatively persistent beds, particularly in the Newcastle and Keele Groups, and are used to a limited extent for correlation of sections in particular coalfields. They are supposed to have been formed by the evaporation of sheets of shallow lime-charged water. Some show a fragmental structure due to the cracking of the sun-dried carbonate of lime, followed by re-sorting of the broken material by water. In origin they are similar to the cornstone breccias of the Old Red Sandstone.

Some of the Keele Sandstones are of the type known as ' pellet-rocks,' in which flakes of marl occur. The Keele Beds also include ' fish-eyed ' marls similar to those in the Downton Series. These are bright red mudstones with green spots of various sizes, each with a dark centre. The development of these ' eyes ' is probably the result of local reduction to the ferrous state of ferric compounds responsible for the general red coloration of the rock.

Plant remains, although rare, are occasionally found in the clays.

The group varies in thickness from 700 ft. in Warwickshire to 200 ft. in Shropshire, and rests conformably on the preceding group, except in the neighbourhood of the Wrekin, where renewed uplift led to erosion of the Coalport Beds prior to the deposition of the Keele Beds. The succeeding Enville Beds, sometimes classified with the Barren Red Measures, are described on pp. 48-50.

IGNEOUS ROCKS IN THE COAL MEASURES

Igneous rocks occur in association with Coal Measures at several localities in Central England. Many of them were formerly believed to be intrusions of Tertiary age, but R. W. Pocock has recently shown them to be of Carboniferous age. They may be related to the crustal movements of late Yorkian and Staffordian times. These igneous rocks are confined to a narrow belt of country running E.N.E.–W.S.W. through Ashby-de-la-Zouch, the middle of the South Staffordshire Coalfield, and the Clee Hills. He considers that several of the more important are lava flows, but Dr. C. E. Marshall regards them as intrusive rocks.

The Kinlet Basalt, in the Wyre Forest Coalfield, lies approximately between the Sweet Coal (Yorkian) and the Sulphur Coal (Staffordian) Groups. Its upper surface is slaggy, and decomposed fragments of the rock occur in the overlying conglomerate. At Shatterford, also in the Wyre Forest Coalfield, an igneous rock occurring at the top of the Sweet Coal Group, and originally described as a dyke, is thought by Pocock to be a lava-flow on account of the absence of alteration in the overlying sediment, by its vesicular top, and by the occurrence of ' pipe-amygdales ' at the base. ' Pipe-amygdales ' are vertically elongated vesicles formed by the steam generated at the base of hot lava as it flows over the ground.

The ' dolerite ' of Titterstone Clee Hill which may possibly be a lava flow attains a thickness of about 150 ft., and lies some 180 ft. above the coal of the Great Seam of the Middle Coal Measures. Columnar jointing is well developed in parts of the basalt. It maintains a constant horizon in the Yorkian Coal Measures, although on the west it overlaps on to Old Red Sandstone. The rock is extensively quarried in the district.

A sheet of olivine-dolerite, either a sill or a flow, was encountered in the Middle Coal Measures in a borehole at Claverley between Wyre Forest and the South Staffordshire Coalfield. Intrusive masses of fine-grained dolerite occur in the South Staffordshire Coalfield, and crop out in the Rowley Hills, at Pouk Hill near Walsall, at Wednesfield; and at Barrow Hill near Pensnett. According to T. H. Whitehead the Rowley dolerite shows transgressive junctions and has the general form of a laccolithic intrusio ninto the Etruria Marl. It attains a maximum thickness of over 100 ft.; at its margins it passes into sills a foot or so in thickness. The rock, locally termed 'Rowley Rag,' shows well-defined jointing, usually of columnar type (*e.g.* in the Prospect Quarry near Rowley Regis), and is quarried for road metal. The Wednesfield and Pouk Hill dolerites intrude the Middle Coal Measures. Where these various dolerites have cut through coal seams, the coal has either been destroyed for some distance on either side, or locally converted to the condition of coke or of anthracite.

A sheet of dolerite over 20 ft. thick occurs between the Middle Coal Measures and the Trias at Whitwick Colliery in the Leicestershire Coalfield. The molten material appears to have been intruded along the Thringstone Fault, and to have spread out as a sill. It has been proved over an area of four square miles.

Hercynian Earth-movements

It has been shown that the sediments of the Upper Coal Measures in the Midlands gradually assume a continental facies, in their upward sequence, as a result of earth-movements which at the time of their deposition slowly converted the area into a land-locked basin. Earth-movements manifested themselves at an early stage in the Carboniferous cycle of sedimentation; they gradually increased in intensity and reached a climax at the close of the period, when a new series of mountains was uplifted and the deposits were strongly folded and faulted. In Central England one of the most important effects of these earth-movements was the raising of a series of mountains known to geologists as the 'Mercian Highlands.' These may be regarded as belonging to the outer fringe of the group of mountain ranges raised all across N.W. Europe at this time. The movements are referred to as the Hercynian System.

The effects of early Hercynian movements are traceable in the Coal Measures. Many of the folds and faults affecting these beds were foreshadowed by differential subsidence in the district during the Coal Measures period. The Coal Measures increase in thickness in the troughs and thin towards the crests of local folds; this is particularly well seen in the Potteries Syncline and the adjacent Western Anticline. This arrangement clearly indicates the development of folds during the actual deposition of the Coal Measures. Again, Wickham King has found that movement took place along the line of the Mucklow Hill Fault in the South Staffordshire Coalfield, during Staffordian times. Contemporary igneous activity is further evidence of the instability of the region during this period.

Some of the local breaks in the Coal Measures of Central England have already been noted, the most noteworthy being the ' Symon Fault ' in the Coalbrookdale Coalfield (p. 46). Re-elevation of the Wrekin-Longmynd area led to erosion in pre-Keele times, while limestone breccias in the Keele Beds near Bridgnorth provide evidence of the first important rise of the Worcestershire block of the Mercian Highlands.

Local unconformities are frequent in Upper Coal Measures in the neighbourhood affected by the growth of the Mercian Highlands; for instance, unconformities occur at the base of the Halesowen Beds in South Staffordshire and at the base of the Enville Breccias in Wyre Forest.

During, and subsequently to, the deposition of the uppermost Coal Measures the Carboniferous rocks were folded and faulted to a considerable degree. Most of the structures of the Midland Coalfields are attributable to this phase of the ' Hercynian earth-storm.' Movement took place in two main directions: (*a*) compression of the rocks in the Carboniferous geosyncline led to the development of numerous north-south folds, of which the Malvern and Pennine lines of uplift are the most apparent; (*b*) a minor system of east-west folds was developed, one of these being the fold which separates the Nottinghamshire from the Leicestershire Coalfield.

The main movement of the great Coalfield faults of Central England has been shown to be of pre-Triassic date, although in most cases movement continued both during and after the deposition of the Trias.

Coalfields of Central England

Coal Measures originally formed a thick continuous sheet of strata covering the whole of the northern part of what is now Central England. This sheet was folded and faulted by the Hercynian earth-movements, dissected by erosion, and then buried deeply below thick deposits of Triassic age. Subsequent erosion has removed much of the Triassic cover, and portions of the folded sheet have now become the visible coalfields of the region. There are six important coalfields, namely those of North Staffordshire, Leicestershire and South Derbyshire, Warwickshire, South Staffordshire, Wyre Forest and Coalbrookdale; all belong to the Midland Coalfield Province.

All these coalfields are elongated in a north-south direction in conformity with the main direction of folding. The Coal Measures have been preserved mainly in downfolded areas, the upfolds, as already stated, having been subjected to intense denudation at various periods. Indeed, in some of the areas of newer rocks bordering the visible coalfields, bore-holes have proved the complete removal of the Coal Measures by pre-Triassic erosion, the Trias there resting directly on pre-Carboniferous rocks. Coal Measures are absent, for instance, along the line of east-west anticlinal folding which separates the Nottinghamshire–Yorkshire Coalfield from that of Leicestershire. Over considerable areas in Central England, however, Coal Measures are present below the Trias.

The exposed coalfields of the region occupy an aggregate area of over 600 square miles. The Middle Coal Measures are the chief productive group in Central England; the Upper Coal Measures, exposed in all but the Cheadle and Leicestershire Coalfields, contain only a few thin, and for the most part unworkable, seams of sulphurous coal.

The Middle Coal Measures yield important house, steam, manufacturing and coking coals.

The North Staffordshire Coalfields.—These comprise the Potteries Coalfield on the west, and two smaller ones on the east—the Shaffalong and Cheadle Coalfields.

The Potteries Coalfield covers a triangular area of just over 100 square miles. Its broad structure is that of two anticlines diverging from the apex of the triangle in the north, and enclosing a broad median syncline (*see* p. 32). The base of the triangle is irregular and is delimited by the overlapping Triassic rocks which conceal the Coal Measures as these dip southwards. The western margin of the exposed coalfield is defined by the Red Rock Fault and parallel fractures; the eastern side is formed by the flank of the anticline which brings up Millstone Grit. The median syncline is broken by large faults, the chief being the Apedale Fault which extends in a north-south direction for over nine miles, and which, to the west of Newcastle-under-Lyme, has a throw of over 2,000 ft. The Pottery Towns lie along the central axis of the coalfield.

The Shaffalong Coalfield is a narrow basin of Productive Coal Measures lying beyond the eastern anticline of the Potteries Coalfield and has an area of two square miles.

The Cheadle Coalfield occupies a roughly diamond-shaped area of about eighteen square miles immediately to the east of the Shaffalong basin, and forms low table-land.

The Leicestershire and South Derbyshire Coalfield.—This coalfield has an area of about seventy-six square miles, of which twenty-four square miles are uncovered, the remainder being concealed by Trias. The exposed rocks of the coalfield all belong to the grey series, but some Upper Coal Measures are preserved below the Trias. The coalfield is crossed by an anticlinal fold striking N.W. and S.E. through Ashby-de-la-Zouch, and in consequence the Lower Measures crop out in the middle of the coalfield, with the Middle or Productive Measures on the eastern and western flanks. There are important concealed extensions of the coalfield both on the west and on the south-east. The median anticline of the coalfield is bounded on the east by the Thringstone Fault, which is estimated to have a throw of 2,000 ft. at Whitwick; it extends north-westwards through Ticknall, beyond which it disappears below the Trias. The whole of the displacement appears to have been pre-Triassic.

The Warwickshire Coalfield.—This coalfield has a narrow oval outline, and covers an area of about 150 square miles, extending from Tamworth in the north to Warwick in the south. In its widest part is is only about eight miles across. The greater part of the surface of the visible coalfield is occupied by barren Upper Coal Measures, the Productive Measures cropping out as a narrow band only on the eastern and northern margins. The structure is that of a north-south syncline with a subsidiary anticline in the centre, and with faulted margins; pre-Carboniferous rocks are brought up on either flank at Dosthill and Nuneaton. A narrow concealed extension of Coal Measures has been proved on the south-east of the visible coalfield, but a few miles east of Coventry boreholes pass directly from Triassic Beds into pre-Carboniferous strata. A ridge of Pre-Cambrian rocks underlying

Trias separates the Leicestershire from the Warwickshire Coalfield.

The South Staffordshire Coalfield.—Elliptical in shape, this extends from Rugeley in the north to the Lickey Hills in the south, a distance of some twenty-five miles; it is bounded on the west and east by great displacements known respectively as the Eastern and the Western Boundary Faults. Important extensions of the Coalfield are concealed by Trias between Cannock and Stafford and at least as far south-east of Rugeley as Whittington Heath, near Lichfield, where a succession of Productive Coal Measures closely comparable with that of Cannock Chase has been proved in a trial boring.

The Coal Measures rest directly on an irregular floor formed of Downtonian and Silurian rocks which locally form the steep-sided ridges referred to as 'Silurian banks' (*see* p. 35). Broadly speaking, the coalfield is a denuded anticline with a north-south axis, separating two synclines, the Wolverhampton and Birmingham sub-basins, now concealed by Trias. The main anticline is broken by the three minor anticlines of Dudley, Sedgley and Barr in which Silurian rocks are exposed; synclinal areas, much broken up, intervene between these minor anticlines. An important transverse line of faulting cuts off the northern third of the visible coalfield from the remainder; another important line of faulting extends from near Dudley to the Lickey Hills. The first line comprises the Bentley Faults and the second the Russell Hall Faults.

The Coalbrookdale Coalfield.—The Coalbrookdale Coalfield extends from near Newport to south of Broseley. An important north-east to south-west dislocation, the Boundary Fault, forms the north-western margin of the coalfield, and a series of strong faults, parallel to the Boundary Fault, complicates the structure of the area.

It was at Coalbrookdale that Abraham Darby for the first time used coal for smelting ironstone on a commercial scale, and that cast-iron work was made possible by Darby's introduction of sand-moulds. In 1788 Darby's grandson constructed the first iron bridge—namely that which spans the Severn at Ironbridge—with iron extracted from the ironstones of Coalbrookdale (*see* Plate VIII A).

The important unconformity between the Coalport Beds and the Middle Coal Measures has become known as the 'Symon Fault.' Part of the Symon Fault is illustrated, in diagrammatic form, in Fig. 11. Between Linley and Billingsley, the Middle Coal Measures have been completely removed by pre-Staffordian erosion, and the Coalport Beds rest directly on the Silurian or Old Red Sandstone.

The Wyre Forest Coalfield.—This commences near Bridgnorth, and joins the Coalbrookdale Coalfield by a narrow outcrop of Coal Measures. Southwards the outcrop broadens and extends along the Severn Valley to the latitude of Bewdley. The coalfield is joined to the Mamble Coalfield, to the south, which extends to the Abberley Hills.

The western margin of the coalfield is defined by the main outcrop of the Old Red Sandstone; except at Heightington and Trimpley, where inliers of Old Red Sandstone are brought up along the Malvern axis of uplift, the eastern margin is formed by the Enville Fault.

The strata rest unconformably on Old Red Sandstone. The main coal-bearing series is known as the 'Sweet Coal' or Kinlet Group. This comes

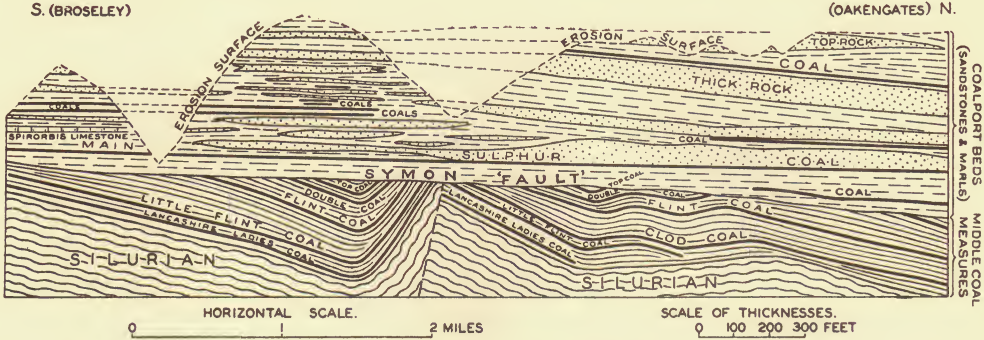


FIG. 11.—*Reconstructed section through the Coalbrookdale Coalfield, showing the unconformity termed the Symon ' Fault ' between the Upper Coal Measures (Coalport Beds) and the Middle Coal Measures* (after T. H. Whitehead)

Folds subsequent to the deposition of the Coalport Beds have been eliminated by taking the Sulphur Coal as a datum line; in consequence, the erosion surface in the diagram does not represent the present topography.

to the surface in the Dowles Valley, and in the western part of the coalfield near Kinlet itself. The Sweet Coal Group (or Yorkian Measures) is 1,000 ft. thick in the Highley region, and includes workable coal seams which in contrast to some of the coals of the Upper Coal Measures of neighbouring coalfields are ' sweet ' (*i.e* non-sulphurous), and furnish both house and steam fuel.

Although the coal seams are normally accompanied by grey shales, red and mottled marls and espleys occur in the Sweet Coal Group, both below and above the workable coals. Conditions of sedimentation generally associated with Upper Coal Measures appear to have commenced earlier in this coalfield than elsewhere in the Midlands.

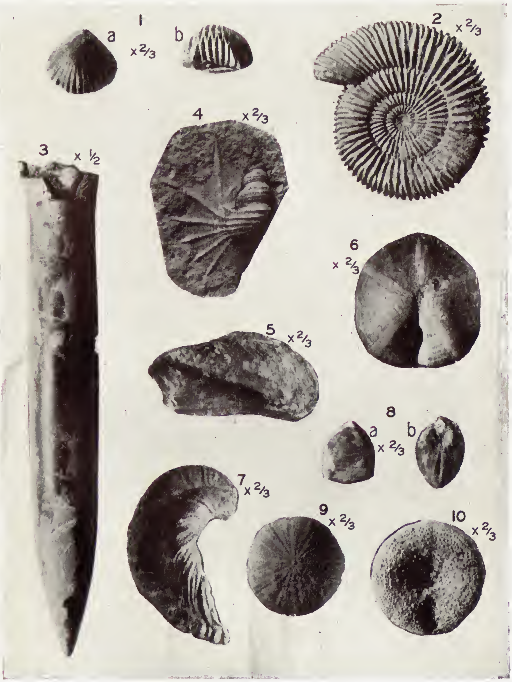
In the Titterstone Clee district Productive Coal Measures, resting unconformably on the Cornbrook Sandstone, occupy an area of about four square miles. They consist of grey shales and sandstones, with reddish clays and three workable coal seams, which, however, are no longer worked. Several shafts to these seams were sunk through a thick mass of dolerite which occurs above the Great Seam (*see* p. 42). The greater part of the measures preserved are of Yorkian age, but Staffordian plants occur in the upper beds. A small patch of Productive Coal Measures occurs at Brown Clee Hill to the north, and is capped by dolerite.

VIII. ENVILLE BEDS, AND THE PERMIAN SYSTEM

THE ENVILLE BEDS, included with the Coal Measures on Plate I, which succeed the Keele Group (p. 41), constitute a series of red rocks, generally classified with the Upper Coal Measures, but which are possibly in part of Permian age. The strata consist of red marls and red calcareous sandstones, with local thick beds of calcareous conglomerate in the lower part, and of breccia in the upper part. The Enville Beds in South Staffordshire are subdivided into a lower or ' Calcareous Conglomerate Group,' and an upper or ' Breccia Group.' More recent terms are ' Bowhills Group ' for the lower subdivision and ' Clent Beds ' for the upper.

The Enville Beds were accumulated under semi-arid conditions, evidence for this conclusion being the presence of pellet-rocks, footprint beds, rain-spot impressions and sun-cracked surfaces at several horizons. The jasperized condition of the cherts in the conglomerates indicates desert conditions, while the extensive formation of breccia-fans point to mechanical, as opposed to atmospheric, weathering of bare rock-surfaces.

These beds, largely products of erosion of the Mercian Highlands, were laid down in an inland basin. They attain a maximum thickness of 3,500 ft. in Warwickshire, but thin westwards to 1,000 ft. in South Staffordshire, and to 700 ft. in the Wyre Forest. In the Warwickshire area, which was probably the centre of the basin, no important break is known in this district either at the base of, or within the Enville Series. While the Enville Beds were being laid down, the Mercian Highlands were undergoing periodic elevation, and the conglomerates and breccias which occur at intervals throughout may mark periods of uplift, when erosion would be increased,



CHARACTERISTIC JURASSIC FOSSILS

1. *a* and *b* *Tetrarhynchia tetrahedra* (J. Sowerby)—Lias. **2.** *Dactylioceras directum* (S. Buckman)—Lias. **3.** *Cylindroteuthis oweni* (Pratt)—Oxford Clay. **4.** *Phyllocheilus* [*Malaptera*] *bentleyi* (Morris and Lycett)—Collyweston Slate. **5.** *Modiolus imbricatus* J. Sowerby—Great Oolite. **6.** *Echinobrissus orbicularis* (Phillips)—Cornbrash. **7.** *Gryphaea arcuata* (Lamarck)—Lias. **8.** *a* and *b* *Digonella* (*Ornithella*) *digona* (J. Sowerby)—Great Oolite. **9.** *Holectypus depressus* Lamarck, dorsal view—Cornbrash. **10.** *Holectypus depressus* Lamarck, ventral view—Cornbrash.

(*MN2767*)

OPEN WORKING IN NORTHAMPTON IRONSTONE, CORBY (PHOTOGRAPH OF DIORAMA IN GEOLOGICAL SURVEY MUSEUM)

[*To face page* 49

and the transporting power of rivers greatly accelerated. It was only at the margins of the basin, close to the rising mountains, that uplift and erosion resulted in actual unconformities; in the Wyre Forest, and in the southern part of the South Staffordshire Coalfield an unconformity has been traced at the base of the Breccia Group. This unconformity appears to be relatively widespread although not extending into Warwickshire.

Although the Enville Beds usually succeed the Keele Beds without marked unconformity, they were deposited over a more restricted area. They are exposed in the Wyre Forest, Coalbrookdale, South Staffordshire and Warwickshire Coalfields, and have been proved in a bore-hole near Stratford-on-Avon. Some calcareous red beds exposed in Keele Park, North Staffordshire, may also belong to the Enville Beds.

Recent studies of the conglomerates and breccias of the Enville Group have thrown considerable light on the denudation and rock composition of the Mercian Highlands. The Enville Conglomerates are largely composed of pebbles of limestone and chert of Carboniferous age mixed with pebbles of older rocks, in relative proportions varying considerably from place to place. The material appears to have been of strictly local derivation. L. J. Wills, in discussing the conglomerates in the West Midlands, remarks that the different ' make-ups ' agree with what is known of the underground composition of the country adjoining each occurrence on the south and south-east. Conglomerates near Abberley, for example, contain pebbles of the dolomitic type of Wenlock Limestone which is peculiar to that district, whereas contemporary conglomerates of South Staffordshire contain pebbles of the Dudley type of Wenlock Limestone, and also of the local Cambrian quartzite. From the high proportion of Carboniferous Limestone pebbles in conglomerates of South Staffordshire and the Enville district, it is concluded that Carboniferous Limestone cropped out over large tracts of the Mercian Highlands between the sites of the Wyre Forest and South Staffordshire areas, and probably again to the east of the site of Birmingham. The Enville Conglomerates, which occur in lens-shaped masses passing laterally into sandstones and marls, represent pebble-gravels laid down in delta-fans which spread out and coalesced at the foot of the Mercian Highlands. Conglomerates have been traced at five levels in the Enville Group in the Warwickshire Coalfield by F. W. Shotton. They are named in ascending order—the Arley (Exhall), Corley, Allesley, Beechwood and Gibbet Hill conglomerates. The Corley conglomerate is the main water-bearing horizon in the Coventry district; it is largely composed of pebbles of Llandovery sandstone derived from a former outcrop of that formation to the south-east.

In the Coventry district a progressive increase in the proportion of pebbles of pre-Carboniferous rocks is to been seen as the beds of conglomerate are traced in upward sequence; this indicates that as erosion of the mountain ranges proceeded, successively older rocks were exposed to denudation.

The Enville (Clent) Breccias, which are interstratified with marls and sandstones, represent rock-screes spread out from the Mercian Highlands. These scree-deposits, which probably flanked the slopes of the Mercian Highlands, from the Malverns in the west to the borders of Charnwood in the east, may be compared with the extensive breccia-fans forming at the present day on the desert plains of Peru. The Enville Breccias consist of angular fragments of rock, with a glazed coating of haematite, in a marly matrix. The fragments are of many sizes, the majority measuring from 2 in. to 6 in. across, but blocks up to 2 ft. across have been recorded. The lack of rounding, together with the large size of the fragments, suggests that the breccias were rapidly accumulated under the influence of torrents.

The conglomerates consist mainly of Carboniferous and Silurian rocks; the breccias are largely composed of fragments of rocks older than the Silurian, particularly of Pre-Cambrian rocks. On account of the high percentage of pebbles of Uriconian volcanic rocks in the breccias of the West Midlands, they are often referred to as the ' trappoid ' breccias. The abundance of Uriconian rock-fragments in the Clent Breccias near Birmingham indicates that outcrops of Uriconian rocks formerly existed between the Wyre Forest and South Staffordshire.

The Enville Breccias are highly resistant to erosion, and their outcrops form well-defined ridges, such as the escarpment of the Clent Hills to the south-west of Birmingham. They are well developed in the Wyre Forest Coalfield, cropping out between Enville and Claverley, at Bowhills, and along the line of the Eastern Boundary Fault, capping Castle Hill, and again at Warshill in the Abberley Hills. They crop out along the western margin of the South Staffordshire Coalfield, for example, in the Lickey, Clent and Walton Hills, and further east in the same coalfield at Frankley, Northfield and Warley.

In the Warwickshire Coalfield the Enville Breccias are developed on a smaller scale than in the West Midlands. Two breccia beds, occurring in the midst of a thick sandstone group, have been recognized at Kenilworth.

Fossils are extremely rare in the Enville Group; plant remains have been found at several levels in the Corley Beds of Warwickshire, and include impressions of leaves of *Walchia*, and *Asterophyllites*, and silicified wood of *Dadoxylon* and *Cordaites*. Footprints of amphibia have been found at several localities, for example at Hamstead, and in the Whitemoor Brickworks near Kenilworth. At Slade Heath in Staffordshire, specimens from a borehole indicated the existence of a footprint bed; one specimen showed the tracks of a small lizard-like reptile.

The question whether the Enville Beds are of Upper Carboniferous age or of Permian is a matter of discussion. The beds were originally referred to the Permian; the absence of a major unconformity at their base, however, has led to their inclusion in the Upper Coal Measures. It is possible, nevertheless, that in the Midlands sedimentation continued uninterruptedly through uppermost Coal Measures and earliest Permian times, and that at least part of the Group belongs to the Permian System.

IX. TRIASSIC SYSTEM

THE TRIAS IS the most widespread system in Central England. It forms the low-lying, gently undulating country of the Midland plain, covering large areas of Shropshire, Worcestershire, Warwickshire, Leicestershire and Staffordshire. The outcrop, Y-shaped in form, extends from the central area along three belts. The two northern belts extend beyond the present region, and lie on either side of the Pennines. The third belt runs south-westwards into Gloucestershire.

Triassic deposits were probably accumulated in a basin surrounded by high mountains, and with an internal drainage system, under a climate which was mainly hot and arid, although sometimes tempered by moister and perhaps cooler conditions. The beds consist of sandstones, pebble beds and marls, predominantly red in colour. The colour, considered to be an indication of contemporary desert conditions, is produced by a thin film of iron oxide coating each of the constituent grains—a condition probably connected with a general lack of vegetation at the time of deposition of the rocks. The deposits were partly wind-borne, partly laid down by torrents and partly deposited under sheets of standing flood-water.

Hercynian earth-movements reached their climax in the Midlands soon after the deposition of the Coal Measures, and the older rocks were then uplifted to form a mountainous area considerably exceeding in extent the Mercian Highlands of the Carboniferous period. These mountains were subjected to intense denudation, while concurrently parts of the area gradually subsided, so that the erosion products were accumulated in an irregular basin which owed its form partly to earth-movements, and partly to erosion; the Trias is thickest in Cheshire and North Shropshire, where the basin was deepest. The component subdivisions of the Trias, when traced to the south-east, are seen to become thinner and to overlap the one below, and ultimately to rest on an eroded surface of older rocks. In Charnwood Forest, which was one of the last areas to be buried by Triassic deposits, only the highest beds of the Trias are present, and they rest directly on a worn surface of Pre-Cambrian rocks. With the removal of these Triassic deposits by recent erosion, the rugged topography of the buried Triassic land-surface is being gradually revealed (*see* p. 57 and Plate V B).

As a result of the denudation of the Triassic mountains, weathered rock material accumulated on the hill-sides and occasional tropical rainstorms swept the loose material on to the lower-lying areas, where it became sorted by wind and water, and formed the coarser beds of the lower divisions of the Trias. With the destruction of the hills, and the filling up of the depressions, the country approached flatness; as a consequence seasonal floods became less torrential and lost their transporting power, and coarse sediments gradually gave place to finer-grained silts which were spread out on the plain, and redistributed by wind. During this latter phase wide shallow salt-lakes came into existence. The absence of free drainage, and the excess of evaporation, led to high salinity, and ultimately to the deposition of masses of rock-salt. In some areas deposits of gypsum and anhydrite were also accumulated. Following Ramsay and Hull, R. L. Sherlock, on whose work much of our knowledge of the Trias is based, considers that these salts were precipitated from the waters of an arm of sea which gained temporary access to the Triassic basin, and which was subsequently cut off and converted into a ' dead ' sea. A map showing the hypothetical geography of that time is shown in Fig. 12.

Triassic strata are divided into a lower group, the Bunter Series, and an upper, the Keuper Series. The Bunter is subdivided into three, the Lower

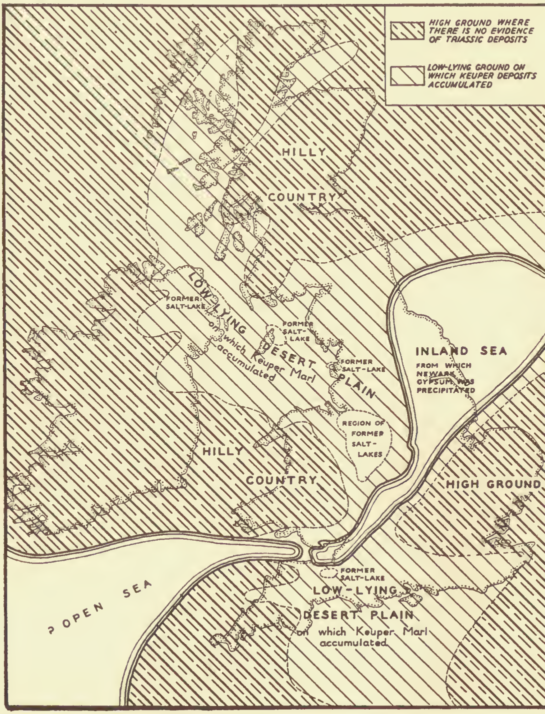


FIG. 12.—*Palaeogeographical map for the end of the Keuper Epoch; (the time of the formation of the Upper, or Newark Gypsum). The position of the British Isles is shown in outline. (Partly based on Sherlock and Stamp.)*

Mottled Sandstone, the Pebble Beds and the Upper Mottled Sandstone. The Keuper consists of Keuper Sandstone below, and Keuper Marl above; the Keuper Sandstone is again separable into Basement Beds, Building-stone

Group and Waterstones; the topmost beds of the Keuper Marl constitute the Tea-Green Marls.

The Trias rests with marked unconformity on all older rocks. It originally covered the whole of Central England, but it has been removed from large areas by erosion, and in many districts the older rocks underlying it have been exposed (*see* p. 7). In the east and south-east of the region the Trias is itself buried beneath newer rocks.

The thickness of the Trias is extremely variable; it is estimated to be over 2,500 ft. to the north of Bridgnorth, 1,500 ft. at Birmingham, and 500 ft. below the Jurassic Beds near Rugby. Triassic deposits probably never extended far to the south-east of their present outcrop; borings at Orton, Oxendon and Gayton in Northamptonshire proved only a few feet of them, mainly coarse, showing that these places are near the original limits of deposition. Generally the prevailing colour of the rocks is red, but there are subordinate beds of buff, green, brown and white. The red soil which marks the outcrop of the Trias is a characteristic of the Midland country.

Bunter Series

The triple division of the Bunter is best seen in Shropshire, near Bridgnorth, and it persists throughout that county and through Staffordshire, but away from that region, one or more divisions are generally absent.

The Lower Mottled Sandstone.—Usually composed of fine-grained sandstone with local marly bands, this subdivision is bright red in colour, with streaks and patches of yellow, sometimes with a greenish tint. Some of the sandstones show large-scale diagonal bedding (Plate V A), indicating that they were most probably deposited as sand-dunes, a conclusion supported by the abundance of round wind-polished sand-grains. Recent study of the orientation of dips of the false-bedding in the Lower Mottled Sandstone has shown that the prevalent wind blew from the east. In Shropshire the Lower Mottled Sandstone is from 80 ft. to about 610 ft. thick; it is also present in South Nottinghamshire.

At the base of the succeeding division there occurs locally a calcareous breccia. To the east of the Coalbrookdale and Wyre Forest Coalfield this bed gives rise to a well-defined escarpment. At Kinver Edge artificial ' rock-houses ' have been hollowed out in the scarp-face of the Lower Mottled Sandstone immediately under the outcrop of the basement-breccia of the Pebble Beds.

Triassic breccias represent re-sorted screes from the mountains. In some areas breccias underlying the Pebble Beds rest directly on older rocks, and they may be, in part, the local equivalents of the Lower Mottled Sandstone. Such are the pebbly Barr Beacon Beds, and the quartzite breccias of South Staffordshire.

Some other breccias rest directly on the Coal Measures, but these are usually separated from the Triassic sandstones by a plane of erosion. These include the Hopwas Breccia which comes to the suface along a narrow belt of country north of Birmingham, and the Moira Breccia to the west of the Leicestershire Coalfield. They are similar in character to the Enville breccias (p. 49) with which they have been sometimes grouped, but

T. Eastwood has found that they have been affected by later movements than those which affect the Enville Series, hence they are more likely to be scree-deposits of early Triassic age.

The Pebble Beds.—These consist of coarse-grained, brownish-red, false-bedded sandstones with well-worn pebbles which vary in size from ¼ in. to about 9 in. in diameter; a few are even larger. In some places pebbles are sparingly scattered throughout the sandstone; at others they are arranged in bands; and at others again they form great lens-shaped masses. On Cannock Chase, for instance, the pebbles occur in such great abundance that they form actual conglomerates, with more or less consolidated interstitial matter. The Pebble Beds attain a thickness of about 600 ft. in Shropshire; they extend into Leicestershire, and are more widespread than the Lower Mottled Sandstone.

They appear to have originated as desert delta-fans formed by intermittent torrential rivers. Several rivers may have flowed into the Midland basin from different directions, all contributing to the formation of the Pebble Beds, for no single source is likely to have provided the variety of rock types which is to be found in them. The sands appear to have had mainly a northerly origin, but some of the pebbles probably came from far to the south, while others were derived from local hills. A high proportion of the pebbles consists of a fine-grained liver-coloured quartzite; this rock

FIG. 13.—*The Hemlock Stone, Bramcote, Notts.*

has never been matched exactly in any known outcrop, although suggested sources range from Scotland to Brittany. The quartzites are thought by some geologists to have been derived by the erosion of local hills, the stumps of which have now been buried; the general opinion, however, is that these pebbles came from a distance. Undoubted local rocks such as Llandovery Sandstone, Lickey Quartzite and Carboniferous Limestone, are represented in the Pebble Beds, but they have a more restricted distribution than the quartzites. There are also pebbles of metamorphic rocks and igneous rocks.

The Pebble Beds, which usually give rise to a hummocky topography, on account of the lens-shaped masses of pebbles, are well developed in Sutton Park, near Birmingham, and on Cannock Chase. At Bramcote a few miles to the west of Nottingham, there is an interesting erosional feature, the Hemlock Stone, a stack standing some 25 ft. high. The greater part of the stack is composed of fairly soft sandstone, which has been protected from complete sub-aerial erosion by a mass of conglomerate cemented by barytes, which now forms an overhanging cap-stone. Fig. 13 shows a sketch of this stack.

The Upper Mottled Sandstone.—Somewhat resembling the Lower Mottled Sandstone in colour, the Upper Mottled Sandstone is mainly a water-laid deposit. It is about 250 ft. thick in Shropshire, but thins towards the east, and is not known far beyond Birmingham. Its original extension was less than that of the underlying Pebble Beds. Sand from this subdivision is extensively worked around Birmingham for use as moulding sand in the iron and brass foundries.

Lens-shaped marly beds occur sporadically throughout the Bunter Beds. These lenses vary in thickness from a few inches to a foot or two, and probably represent small pools which became filled with blown dust. They contain locally carapaces of the minute bivalved crustacean '*Estheria*,' the only fossils known from the Bunter Beds of Central England. At the present day '*Estheria*' lives in fresh or brackish water, and is capable of withstanding wide ranges of temperature and excessive drought.

Keuper Series

The Lower Keuper Sandstone.—This sandstone represents a considerable extension of the basin of deposition of the Trias. In the west it is conformable to the Upper Mottled Sandstone, but to the east it either overlies the Pebble Beds with slight unconformity, or else oversteps on to older rocks. The thickness of this division varies from 100 to 400 ft. in Central England.

The Basement Beds consist of sandstones with conglomerates and local breccias, but the bulk of the Keuper Sandstone is fine to coarse-grained and frequently current-bedded, suggesting that it originated in temporary lakes. The sandstones above the Basement Beds are usually evenly bedded, and are brown, yellow or white in colour. They have been extensively quarried for building stone. Buff-coloured freestone is obtained at the present time from the Keuper Sandstone at Grinshill, near Shrewsbury, while large disused quarries along the outcrop, north and west of Wolverhampton (*e.g.* at Penkridge and Tong), indicate the extent to which the stone was formerly worked. The sandstone at Grinshill has yielded reptilian remains.

The upper part of the Lower Keuper Sandstone is known as the Waterstones; these are passage beds to the overlying Keuper Marl. They consist of a series of brownish micaceous sandstones, alternating with red silty marls and shales, and are so named on account of their banded appearance (cf. ' watered silk ') and not because of any water-bearing properties. In Nottinghamshire they rest directly upon the Pebble Beds.

The Lower Keuper Sandstone is the only division of the Trias in Central England which has yielded fossils in any quantity or variety. While conditions during the deposition of the Trias were on the whole unfavourable to both animal and plant life, the lacustrine conditions leading to the formation of the Keuper Sandstone were more suitable. A fair variety of plants and animals from the Waterstone Group at Bromsgrove has been described by L. J. Wills. These remains occurred in lenses of marl and marl-conglomerate, and included such forms as might have lived in rivers or pools or on their banks, for example, the lung-fish *Ceratodus*, and amphibia.

There are also present derived remains of terrestrial animals including scorpions and carnivorous dinosaurs. The occurrence of the scorpions is a further indication of a hot climate and low rainfall. Plant remains from Bromsgrove include the horsetails *Schizoneura* and *Equisetites*, and *Voltzia*, an early conifer. The leaves of the plants appear to have been tough and leathery like those of living types adapted to an arid environment.

The Keuper Marl.—The Keuper Marl forms a thick and widespread series which overlaps all the earlier beds and occupies considerable areas in Worcestershire, Warwickshire, Leicestershire and Cheshire. In Cheshire, the original centre of the Trias basin, it attains a thickness of over 2,500 ft.; in Leicestershire, where it rests directly on Archaean rocks, it has a maximum thickness of 650 ft.

This subdivision follows the Keuper sandstone conformably, and comprises a mass of mainly red and chocolate-coloured mudstones, with subordinate beds of sandstone and shale. The mudstones of the Upper Keuper are traditionally known as ' marls,' but the term may be misleading, since it is generally used to denote a highly calcareous clay, whereas the ' marls ' of the Upper Keuper are only slightly calcareous. They consist largely of clay-minerals mixed with a high proportion of extremely fine quartz dust, of wind-blown desert type, together with minute dolomite crystals, and were largely accumulated in shallow water. The palaeogeography of this time is shown in Fig. 12.

Although the Keuper Marls are for the most part red or chocolate-coloured, locally, green blotches and bands give the beds a variegated appearance. The highest beds, the Tea Green Marls, are almost entirely green in colour.

Thin beds of grey, buff or pink sandstone, often associated with silty shales, occur at intervals in the Keuper Marl, particularly in the lower part. These beds are known as ' skerries.' The sandstones are usually calcareous, and consist of quartz and worn dolomite crystals, together with some felspar and other detrital minerals. Skerries most probably represent detritus washed from the surrounding hills and accumulated in shallow sheets of water. Ripple-marks, sun-cracks and casts of salt-crystals are locally present. Fine lamination and current bedding are common features of these sandstones; Bernard Smith has described, among other features of the skerries, contorted structures which the laminae often exhibit. He attributes these to slumping of current-bedded sands while the deposit was in a soft and plastic condition. " Freshets of water," he says, " producing swirling currents would sweep along with them a heavy burden of sand, and tear up or contort underlying ripple-marked layers, embedding them in a structureless deposit."

Skerries usually occur in groups in which sandstones alternate with marls and shales; to these groups Smith has applied the term ' skerry belts.' In the relatively flat topography to which the Keuper Marl gives rise, almost every hilly feature is the expression of these relatively resistant sandstones.

A fairly thick development of sandstone, associated with blue-grey shales, occurs in the Keuper Marl of Worcestershire, Warwickshire and Gloucestershire, about 120 to 150 ft. below the top of the formation, and attains a thickness of some 40 ft.; this is the Arden Sandstone, one of the Upper Keuper Sandstones of Central England. Locally it has yielded numerous fossils, notably plants, fishes, amphibia and ' *Estheria*.' Mollusca, possibly marine, have also been found in this sandstone, which may represent a temporary incursion of the sea. The chief fossiliferous exposures of the bed are at Pendock near Tewkesbury, and at Rowington and Shrewley in Warwickshire. These Upper Keuper Sandstones give rise to undulating topography, an instance being that of the Forest of Arden itself.

In the Charnwood Forest region a buried Triassic landscape, which has been the subject of a detailed study by Prof. W. W. Watts, is being revealed by the removal, by sub-aerial erosion, of Keuper Marl; the old land-surface is formed of hard Pre-Cambrian rocks and is of a markedly rugged type. Many of the deep valleys of the Charnwood Forest were cut in Triassic times along shatter-belts or fault-lines, and have now been re-exposed. The steepness of the buried mountain slopes may be gauged by the great variation in the thickness of the Keuper Marl within short distances.

Small-scale features of the old desert surface are revealed in the course of quarrying operations. Locally the Marl fills U-shaped gullies which resemble the wadis of modern deserts. One of these, cut in Pre-Cambrian slates, has been revealed in a quarry at Woodhouse Eaves (*see* Plate V B). At Mount Sorrel the granite against which the Marl is banked shows smoothed and terraced surfaces caused by sand-blast action. Dr. F. Raw considers that in part some of these features may have been produced by similar action during late Pleistocene times.

Beds of massive gypsum precipitated during the evaporation of a ' dead sea ' occur at two horizons. The lower bed occurs at about 140 ft. below the top of the Keuper, and has been mined at East Leake in Leicestershire, at Chellaston near Derby, and at Fauld near Tutbury in Staffordshire. The close-textured gypsum of Fauld and Chellaston has been worked for many centuries as ornamental alabaster. The upper beds occur at about 60 ft. from the top of the Keuper, and are worked at Newark, and at several places between Nottingham and Leicester. Strings and nodules of fibrous gypsum are common throughout the Keuper Marl.

Rock-salt deposits form two thick beds in the Keuper Marl of Cheshire and have been extensively worked in the Northwich-Winsford area. Thinner beds of salt occur at the same horizon in Staffordshire and Worcestershire. The salt-deposits were proved in a borehole at Chartley, and were formerly worked at Weston-on-Trent. Rock-salt has also been worked at Droitwich and Stoke Prior.

Rock-salt occurs in lenses. In places it has been dissolved by inflowing surface water, and the bed thereby replaced by a natural brine reservoir. Although at one time the salt was mined, in recent years it has all been obtained by the evaporation of the brine pumped to the surface from wells. Heavy pumping of brine has led in some cases to subsidence of the ground, notably around Droitwich and in the Northwich-Winsford area.

The Keuper Marl is the chief source of rock-salt and gypsum in this country.

The Triassic sandstones and pebble-beds of the Midlands constitute an important source of underground water which, when tapped by wells and bores through a thick impervious cover of Keuper Marl, is frequently under artesian head. The purest water is obtained from the Bunter formation. Water is also obtainable from the Lower Keuper Sandstone, but where the latter is overlain by Keuper Marl the water is usually permanently 'hard.' Water of this type is of great value in brewing, and numerous breweries have been established on the outcrop of the Keuper Marl, as at Burton-on-Trent. Water from the Keuper Beds is sometimes saline, such as that from a spring arising at the juction of the Lower Keuper Sandstone and the Keuper Marl at Leamington Spa, which is well known for its medicinal properties.

Copper ore occurs in the Keuper Sandstone at Alderley Edge, Cheshire, where it was formerly mined.

IGNEOUS ROCKS INTRUSIVE IN THE TRIAS

The Trias is penetrated near Swynnerton in North Staffordshire, and at Grinshill in Shropshire, by dykes of basic rock, which trend from N.N.W. to S.S.E. Their intrusion was connected with the widespread igneous activity of the Tertiary period.

The Swynnerton dyke forms a nearly vertical wall cutting the Keuper Marl; it attains a maximum thickness of 100 ft., but locally it splits into several thin dykes. On account of its high content of iron it is strongly magnetic and it has been found possible to trace its course by means of a magnetic survey.

The Grinshill dyke penetrates both the Bunter and Keuper Series.

X. JURASSIC SYSTEM

BY THE END of Keuper times the surface of the Triassic continent had been more or less levelled; the close of the period was marked by the transgression of a sea, the Rhaetic sea, which spread rapidly over the whole of Central England.

This transgression marks the change from the continental conditions of the Triassic period to the succeeding marine conditions of the Jurassic.

Jurassic strata in England cover much of the south-eastern half of the country, and their outcrop stretches from the Dorset coast to Yorkshire. The individual beds, however, are not of equal thickness throughout; while the structural history of this part of England may be regarded as being one of persistent but intermittent downward movement, certain areas subsided more rapidly than others, thereby producing a series of basin-like depressions in which considerable thicknesses of strata were laid down in the middle, thinning towards the edge. From time to time the rims were also submerged, and over these districts attenuated representatives of the various divisions may be present.

Part of the Midlands constitutes one of these basins, of which the northern rim may be considered to underlie Market Weighton, to the north of the Central England District; the western to lie along the Vale of Moreton, extending northward from Bourton-on-the-Water and Moreton-in-Marsh in the Cotswolds; the southern was the land mass extending eastwards from the present site of London; there is no indication of the eastern boundary of the basin, but it may be under the site of the North Sea.

As a result of silting up of this basin, combined with irregular earth-movement, fluctuations in the depth of the Jurassic sea occurred, with attendant changes from clear to muddy water, and *vice versa.* Deposits include clays, shales, limestones, ironstones and silts.

Many Jurassic limestones are oolitic (Greek, *oon*, an egg), *i.e.* they consist of small, rounded grains and resemble the hard roe of a fish. Limestones of this type are so characteristic of the Jurassic rocks that all strata above the Lias are collectively known as the 'Oolites.'

Many fossils are present in the Jurassic rocks, and amongst the most common are the ammonites (cephalopod molluscs). Myriads of these lived in the sea, their sizes varying from less than an inch to 2 ft. or more in diameter. Jurassic ammonites show rapid evolutionary changes and have proved reliable zonal guides, so that almost the whole of the Jurassic deposits of Britain may be correlated on a zonal basis.

Some characteristic Jurassic fossils are shown on Plate VI.

RHAETIC SERIES

The Rhaetic Beds of Great Britain have in the past either been included in the Trias or else considered as belonging to a separate system. They are now generally classified as the basal beds of the Jurassic System. Their outcrop forms a narrow band running north-eastwards across the Midland Plain, while outliers have been preserved at Knowle, the Needwood Forest district, Barrow Hill near Burton, Prees, and elsewhere. The whole Series is about 30 ft. to 40 ft. thick.

The presence of Rhaetic Beds in the Wem District near Prees, where they form part of the Prees Jurassic outlier, has been recorded on the evidence of highly fossiliferous material now in the Shrewsbury Museum, collected by H. Iken " from a spoil heap of a shaft sunk in a mistaken search for coal three-quarters mile S.E. of Prees Church." L. Richardson considers the fossils to indicate that the material is of the age of the *Pteria contorta* shales.

The junction of the Rhaetic Beds with the underlying Tea Green Marls is usually shown by a sandy or conglomeratic bed with a line of erosion at its base. This bed, the *Ceratodus* Bone-bed, is usually rich in vertebrate remains, particularly in the scales, spines and teeth of fish, such as *Ceratodus*, *Acrodus*, *Hybodus* and *Gyrolepis*.

Black muds were accumulated in the shallow restricted waters of the early Rhaetic sea, and to-day form beds known as the *Pteria contorta* shales, which overlie the bone-bed. A good section in these black shales occurs at the Glen Parva brickworks near Leicester, where, in addition to the lamellibranch *Pteria contorta*, remains of the starfish *Ophiolepis* have been found.

As more open-water conditions developed, the light-coloured marls, sandy shales with calcareous nodules, and creamy limestones, the Upper Rhaetic Beds, were laid down. These pass up without a break into the Lias. The fossils of the upper part of the Rhaetic Beds are mainly lamellibranchs, such as *Pseudomonotis* and *Palaeocardita*.

Lias

The term ' Lias ' was introduced into geological nomenclature by William Smith. It is an old West of England quarryman's term; Buckman considered that it was derived from the Gaelic word ' Leac,' meaning a flat stone; at several horizons in the Lias muddy and shelly limestones occur in thin beds. The formation known to us as the Lias, however, chiefly contains clay. Its outcrop covers a wide belt of country in the south-eastern part of the Central England District. Three subdivisions, Lower, Middle and Upper, have been recognized.

In common with the greater part of the Jurassic strata of the country, the Lias of Central England has been divided into zones on the basis of the contained ammonites. The zones present are as follows:

Upper Lias	Lytoceras jurensis Hildoceras bifrons Harpoceras falcifer Dactylioceras tenuicostatum
Middle Lias (or Marlstone)	Paltopleuroceras spinatum Amaltheus margaritatus
Lower Lias	Prodactylioceras davoei Tragophylloceras ibex Uptonia jamesoni Echioceras raricostatum Oxynoticeras oxynotum Asteroceras obtusum Arietites turneri Arnioceras semicostatum Coroniceras bucklandi Scamnoceras angulatum Psiloceras planorbis

Dr. L. F. Spath has replaced *Harpoceras falcifer* by *Hildoceras serpentinum* as a zonal index fossil.

In Central England Jurassic Strata are almost solely confined to the south-eastern third of the District (*see* Sketch-map, Plate I). They formerly covered much of the ground westward of the main outcrop, however, and probably extended to the Welsh Hills, but have been removed by denudation, except for small remnants left as outliers. The most noteworthy of these cutliers is that near Wem, about seventy miles from the main outcrop.

Lower Lias.—The Lower Lias outcrop occupies the Vale of Evesham and continues through Rugby, Leicester and Melton Mowbray to the north-eastern corner of the district, running thence into Lincolnshire. Tongues extend northward to Droitwich and Henley-in-Arden. A small outlier occurs at Knowle and a second at Prees, on the borders of Shropshire and Cheshire.

The chief rock type is blue shaly clay, but in the lower part hydraulic limestones are strongly developed; these have been extensively worked for the manufacture of lime and hydraulic cement near Rugby, where they are about 75 ft. thick; at Wilmcote, near Stratford-on-Avon; at Barrow-upon-Soar in the Melton Mowbray district; and at numerous other localities. Near or at the base of the Lower Lias of the Midlands several of these limestones are noteworthy for their contained fossil insects, and have accordingly been termed 'Insect limestones.' Similar insect limestones occur in the underlying Rhaetic Beds. In some localities various bands of the Lower Lias limestones received individual names, some of which had relation to the use to which stone was put, others to some characteristic appearance; the origin of others is not traced. A quarry at Binton, for example, is recorded as containing 'Griesley Bed,' 'Pendles,' and 'Guinea Bed.' Various brickyard sections are present along the line of outcrop in Warwickshire and Northamptonshire.

The Lower Lias is about 500 ft. thick in Northamptonshire, but thins to the south-east; it may thicken towards Lincolnshire. Shales with calcareous mudstones are present in the Prees outlier, where the total thickness may be over 400 ft.

Among the fossils recorded from the Lower Lias are the lamellibranchs *Gryphaea arcuata*, *Lima gigantea* and *Hippopodium ponderosum*, the coral *Stylophyllopsis* [*Montlivaltia*] *mucronata* and brachiopods such as *Spiriferina verrucosa*, in addition to numerous ammonites. The pits of Barrow-upon-Soar have long been famous for their reptilian, fish and crustacean remains, collections of which are to be seen in many museums. Fossils include ichthyosaurs and plesiosaurs, the fish *Dapedius dorsalis*, and the lobster *Eryon barrovensis*.

Middle Lias including the Marlstone.—The Middle Lias contains a greater proportion of hard rock to clay than do the other two subdivisions of the Lias. The outcrop in the Midlands runs north-eastward from Edge Hill near Banbury through Daventry and Oakham. Around each of the latter two districts it covers extensive tracts, but between them it is narrow. Several outliers are present to the north-west of the main outcrop.

The north-western boundary is usually a well-marked escarpment, seen particularly well at Edge Hill.

The Middle Lias is some 150 ft. thick at the north-eastern edge of the Central England district, but thins to about 75 ft. in parts of Leicestershire and Rutland. Five subdivisions were recognized in the Rutland deposits by Judd, as follows:

(5) Marlstone rock-bed.

(4) Light blue clays with bands of ironstone balls.

(3) Blue clay with septaria.

(2) Blue highly micaceous clay with large septaria crowded with fossils.

(1) Soft brownish-yellow sandy and micaceous ironstone.

The Marlstone rock-bed everywhere forms the top of the Middle Lias; the remaining beds are less constant in type. The Marlstone has been extensively worked for iron-ore in the Edge Hill district, and in Leicestershire. The best Marlstone ore is dark green oolitic limestone in its unweathered state, but much has been weathered into a soft brown decalcified ore. ' Nests ' of shells of the brachiopods *Tetrarhynchia tetrahedra* and *Lobothyris punctata* are a stable feature of the ironstone. A Marlstone capping is present in the Prees outlier.

In general, the Marlstone is found in the Spinatum Zone, while the associated clays are in the Margaritatus Zone.

Upper Lias.—The outcrop of the Upper Lias is confined to river valleys around Towcester, the greater part of the surface of the country being occupied by newer rocks; northward it covers a wide tract west of Brixworth and Arthingworth; northward again, in the Northampton district, it is to been seen chiefly in the valley sides. The subdivision is on an average about 200 ft. thick, but it thins northward. It consists almost entirely of a blue shaly or sandy clay, with thin bands of limestone. The base is often marked by a very fossiliferous ' Transition Bed ' a few inches thick, consisting of grey friable marl and marly limestone.

It has been remarked above that the Jurassic strata of the Midlands were accumulated in a basin-like depression. Subsidence, however, was not regular, nor was it always greatest in the centre of the basin. Nor again is the Upper Lias of the Midlands of the same age as that of the Dorset region, the latter being the younger. This point has been well brought out by a study of the fossil zones of the Upper Lias, particularly by S. S. Buckman, Beeby Thompson and A. E. Trueman. The different zones, on being traced from north to south, are found to thicken at the expense of the lower ones, and indeed the lowest zones may not be represented in the more southerly districts, nor the higher ones in the north. This appears to be the result of a progressive movement southward of the region of subsidence.

Thus, as Buckman has pointed out, it happens that while the sum of the maximum thicknesses of the zones of the Upper Lias exceeds 850 ft., the actual thickness of the formation is nowhere more than 250 ft., and is often less. This is illustrated by Fig. 14.

Four ammonite zones are present, viz. Tenuicostatum, Falcifer (=Serpentinum, see p. 60), Bifrons and Jurensis, but it has been found advisable to subdivide the Bifrons zone into the subzones of Subcarinata, Fibulatum and Braunianum.

Fossils of the Upper Lias include various species of the ammonites *Dactylioceras* and *Harpoceras*; other common fossils are *Belemnites vulgaris*, *Inoceramus dubius*, *Posidonia bronni* and *Nuculana ovum*.

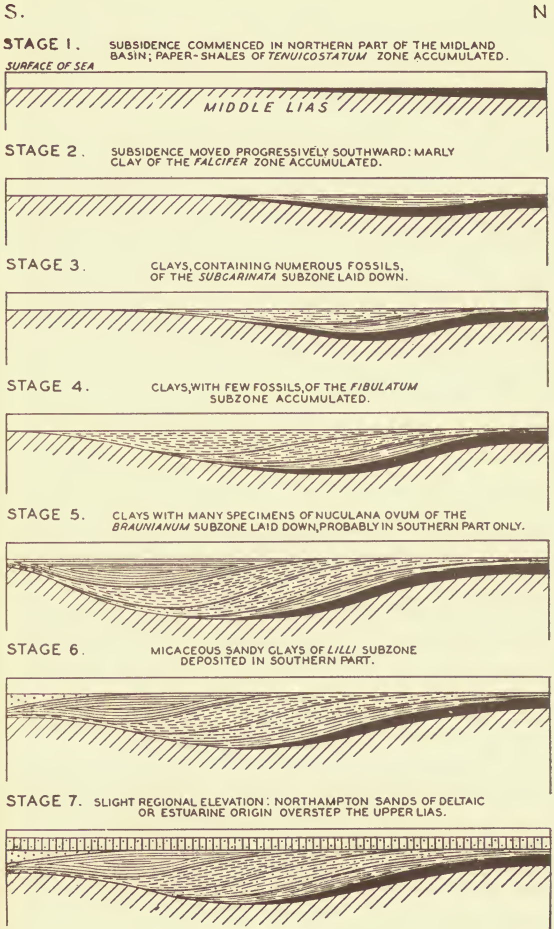


FIG. 14.—*Diagram showing the southward movement of the region of maximum deposition of the Upper Lias in the Midland Basin*

Inferior Oolite Series

The Lias is succeeded by a group of beds of variable type, which include clays, ferruginous sands, silts and oolitic limestones, collectively known as the ' Inferior Oolite Series.' In Central England they comprise, in upward sequence, the Northampton Sand, the Lower Estuarine Series, and the Lincolnshire Limestone, with the Collyweston Slate at its base. The initiation of this Series was marked by a gradual elevation of the sea floor, particularly in the north of our area, and deltaic and fluvio-marine beds were first deposited unconformably on the Lias.

The instability of the region during the deposition of the Inferior Oolite Series is shown by the arrangement of the strata in Northamptonshire and Rutlandshire. In South Northamptonshire the Lower Estuarine Series is overlain unconformably by a somewhat similar formation, the Upper Estuarine Series, of Great Oolite age.

As these strata are traced northwards, a thick bed of oolitic limestone, the Lincolnshire Limestone, gradually intervenes, and around Ketton and Stamford the two Estuarine groups are separated by some 80 ft. of limestone. But to the south-west of Stamford the Lincolnshire Limestone locally rests on the Upper Lias; the site of this district may have been land during the period of deposition of the Northampton Beds, and the lower part of the general sequence may never have been laid down. Again, possibly, for a similar reason the Lincolnshire Limestone is absent south-eastward of a line drawn through Peterborough and Kettering; this is somewhat substantiated by the indication of terrestrial conditions during the Lower Estuarine period referred to below. It may be, however, that parts of these beds were eroded during periods of uplift following their deposition.

Detailed correlation of the Inferior Oolite Series on a zonal basis is far from complete. The general succession of the Middle Jurassic formations in the present area is shown in Fig. 15.

Northampton Sand with Ironstone.—The chief development of the Northampton Sand occurs in the area north-east of Northampton. It extends northward into Lincolnshire, but thins rapidly to the south-east of the Northampton area, and dies out east and south of the River Nene, so that the next overlying series, the Lower Estuarine Series, there rests directly on the Upper Lias.

Seldom exceeding 30 ft. in thickness, although west of Northampton more than twice that thickness has been recorded, the formation consists of a very variable series of sandy deposits, including sands, yellow and orange-brown ferruginous sandstones long valued as building stones, calcareous sandstones, sandy oolitic limestones, and ironstones.

The ironstones average from 6 to 20 ft. thick, but exceptionally are thicker; they originated largely as sea-floor deposits of siderite and chamosite (iron alumino-silicate) deposited by chemical precipitation in the sea of the period. The typical unweathered ironstone consists mainly of chamosite ooliths in a matrix containing siderite (iron carbonate) and calcite (calcium carbonate). In weathered ironstone both iron-bearing minerals are largely altered to hydrated oxide of iron, or limonite.

(*A.2884*)

A. THE GORGE OF THE RIVER SEVERN AT IRONBRIDGE

(*A.1556*)

B. CONTORTED GLACIAL SANDS AND GRAVELS, BUSTLEHOLM, STAFFS.

[*To face page* 64

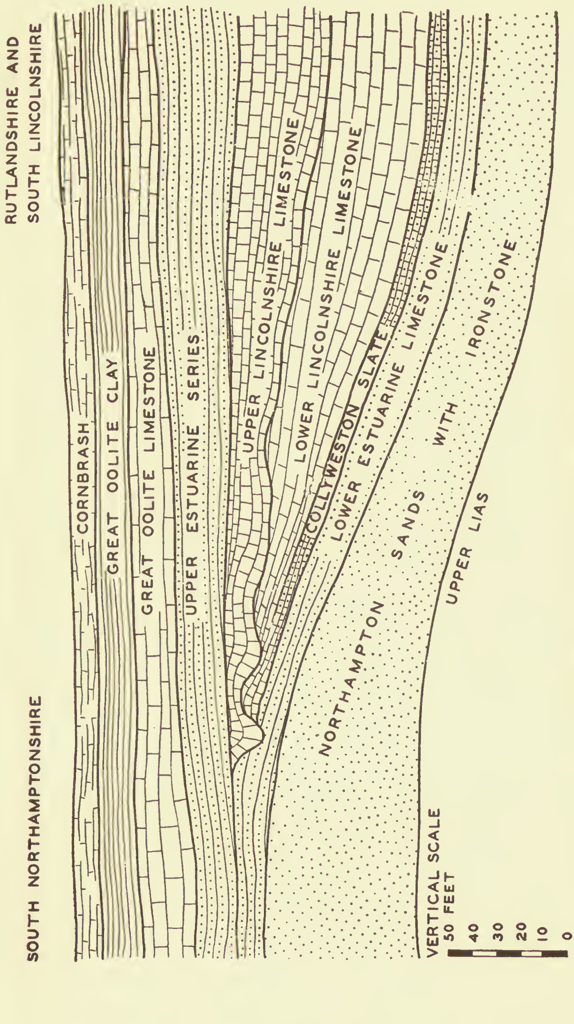


FIG. 15.—*Diagram showing the succession of the Middle Jurassic rocks of Central England*

Iron ore was dug in Roman times, and to-day is extensively worked around Wellingborough, Kettering and Corby. A diorama in the economic gallery of the Geological Survey Museum depicts the Corby workings of the year 1933; a photograph is given as Plate VII. Ironstone is shown as being extracted from a bed 8 ft. thick, the workings forming a trench over a mile long.

Fossils are present usually as 'moulds' and 'casts' and include the ammonites *Lytoceras wrighti*, *Leioceras opalinum* and *Bredyia newtoni*; lamellibranchs such as *Gresslya abducta*, *Ceratomya bajociana*, *Astarte elegans*, *Trigonia v-costata*, and several species of *Lima* (*Plagiostoma*) are characteristic; gastropods such as *Nerinaea cingenda* and brachiopods notably of the genera *Loboidothyris* and *Homoeorhynchia* are common. Exposures are to be seen in the numerous pits, large and small, from which ironstone is being, or has been, extracted.

Lower Estuarine Series.—A series of sands, silts and clays of fluvio-marine origin, normally overlies the Northampton Sands. In general it varies in thickness from place to place from 15 ft. to 25 ft., but it may be much less, and in places may be absent. The sands and silts are extensively worked for refractory minerals for furnace linings.

Locally plant remains are numerous, and a black carbonaceous shale, known as the 'Coaly Bed,' underlain by a band of sandy silt with vertical markings of rootlets, is a widespread feature of this Series. Exposures may be seen in many ironstone workings, notably the Short Leys Pit near Corby and the Lodge Pit near Irchester.

Lincolnshire Limestone.—The Lincolnshire Limestone is composed of a variety of oolitic limestones laid down by chemical precipitation in a clear shallow sea subject to constant agitation by currents, and of shelly detrital limestones. At its base is a sandy fissile limestone a few feet thick, the Collyweston Slate, which marks a passage from estuarine to marine conditions of sedimentation. The main mass of the limestone is about 120 ft. thick in Rutland and Lincolnshire, but thins to zero in South Northamptonshire. At first sight, the fine-grained types are of similar appearance throughout, but they are seen on close examination to vary considerably from place to place. Some of the constituent beds are buff shelly oolites, others are oolites practically devoid of shells varying in colour from pale buff to pink; others again contain much crystalline calcite, and are raggy in character; *i.e.* the limestone breaks into irregular blocks and lumps. Two divisions, an upper and a lower, are recognizable, the upper resting with strong unconformity on the lower, the unconformity being characterized in places by deep channelling, especially along a belt north-east of Kettering. A persistent band containing the brachiopod *Acanthothyris crossi*, present in the thick development of the Rutland area, is included in the missing part of the succession represented by the unconformity in South Northamptonshire.

Parts of the Lincolnshire Limestone yield valuable building stone; several local names have been given to stone quarried from this formation, notably Ketton Stone, of which several Cambridge colleges are built; Weldon Stone, much of which is incorporated in the University Library building at Cambridge, and Clipsham Stone which has been used extensively for repair work on Canterbury Cathedral, York Minster and the Houses of Parliament. Barnack Stone, worked several centuries ago, was used in several cathedrals and abbeys, and in local churches, for example, in Peterborough Cathedral and Barnack Church; it was also used in some of the East Anglian castles. Other local names, *e.g.* 'Ancaster Stone,' are given to the Lincolnshire Limestone beyond the borders of the present region. The limestone was quarried in Roman times, and was used in some of the buildings of *Verulamium* (St. Albans).

The Collyweston Slate has been quarried extensively during the past 400 years for roofing tiles, but at the present time few quarries are in production. The 'slates' were worked either in open quarries or mined from small shafts. Blocks were laid out on the ground, with bedding planes vertical, and kept well watered to prevent drying. Frost action split them into thin layers. It was found that if the blocks once became dry they lost their fissile character.

Fossils are fairly abundant in the Collyweston Slate, and include the lamellibranch *Gervillella acuta* and the gastropod *Phyllocheilus bentleyi.*

The common fossils of the Lincolnshire Limestone are lamellibranchs, *e.g. Pholadomya fidicula*, and gastropods, such as *Nerinaea cotteswoldiae*; small brachiopods and other fossils also occur, but the only ammonites recorded are *Hyperlioceras discites* and its allies.

Good sections of the limestone are to be seen in several ironstone quarries, and at quarries for building stone, and also at a number of abandoned quarries.

Great Oolite Series

The close of Inferior Oolite times was marked by an uplift of the region, possibly greater in the south than in the north; in the south in particular some part of the Lincolnshire Limestone was probably eroded. The deposits first laid down were fluvio-marine in character, and now constitute the Upper Estuarine Series. In South Northamptonshire, on account either of erosion or of non-deposition of the Lincolnshire Limestone, the Upper Estuarine Series overlaps the Limestone, and locally rests on Lower Estuarine beds, and even transgresses over the Lias. On the close of Upper Estuarine times, slight oscillations of the region caused the Great Oolite sea to vary in character from clear to muddy water. Clear shallow-water marine conditions at first obtained, with a reversion later to clay deposition. The beds constituting the 'Great Oolite Series' thus embrace, in upward sequence, the Upper Estuarine Series, the Great Oolite Limestone and the Great Oolite Clay, also known as the Blisworth Clay, which laterally passes into the Forest Marble.

In Central England the Great Oolite Series is almost solely confined to Northamptonshire and Rutlandshire.

Upper Estuarine Series.—The Upper Estuarine Series consists of buff, lavender, green, grey and black silts and clays, together with some shelly beds and limestones indicative of incursions of the sea. A fairly persistent bed, the Upper Estuarine Limestone contains the marine fossils *Ostrea* and *Burmirhynchia.* Plant remains are common, indicating the original proximity of a thickly vegetated land area. The beds vary in thickness from 15 ft. to 45 ft.

Great Oolite Limestone.—The Great Oolite Limestone, laid down in a clear sea, follows the Upper Estuarine Series. It contains fine-grained non-oolitic compact rocks, interbedded with sparingly oolitic to dominantly oolitic freestones, massive rubbly limestones and shelly flaggy limestones. These are usually blue when fresh, weathering to a creamy colour. There are many local variations in the character of the beds, and in the general assemblages of its fossils, which indicate numerous changes in the depth and other conditions under which the deposits were laid down. The formation ranges from 15 ft. to 25 ft. in thickness. Fossils are fairly numerous locally, particularly lamellibranchs; cephalopods, sea-urchins and brachiopods are also fairly common. At Orton an interesting series of fish-remains has been found, including complete palates of such forms as *Mesodon bucklandi.* Good sections are available at Thrapston (Midland Station Quarry), and at various ironstone quarries.

Great Oolite Clay and Forest Marble.—The Great Oolite Clay is inky-blue, black or yellow in colour and about 20 ft. to 25 ft. thick. This clay is of little economic value, and is generally poorly exposed, but may be seen in the section at Thrapston. The Great Oolite Clay passes southwards into the Forest Marble consisting of thin false-bedded limestones with numerous fossils, including the lamellibranch *Chlamys vagans* and the sea-urchin *Acrosalenia spinosa.*

Cornbrash

The Cornbrash is a reddish-brown rubbly oolite, often shelly and flaggy. Although only a few feet thick, the rock has been much dug for local road-stone in the past, but it is now but little quarried and exposures are correspondingly rare. Although thin, both the Upper and Lower subdivisions, traceable in other areas with a greater development, are present. They are marked by a palaeontological break. With the Great Oolite Clay, the Cornbrash forms part of the overburden in quarries for Great Oolite Limestone, at Thrapston. Fossils are common, and include brachiopods such as *Microthyridina lagenalis,* lamellibranchs, as *Goniomya v-scripta, Pholadomya deltoidea* and *Meleagrinella echinata,* sea-urchins, notably *Holectypus depressus* and *Nucleolites clunicularis* and occasional ammonites such as *Macrocephalites.*

Oxford Clay (with Kellaways Beds)

The uppermost Jurassic formation in Central England is the Oxford Clay, consisting of grey-brown and inky-blue clays laid down in the muddy waters of a sea which was in open connection with the northern ocean, together with sandy passage beds, the Kellaways Beds, at the base. The full thickness of this formation is probably about 400 ft. but in our district the upper part has everywhere been removed by recent denudation.

The outcrop of the Oxford Clay covers a large tract around Peterborough, where it is worked extensively for brick-making. Fletton, near Peterborough, is the original home of the ' pressed brick,' or ' fletton,' but bricks of this type are now made from the Oxford Clay in the Bedford district at Calvert, and Bletchley, just outside the present district. The output from the whole group of brickworks in 1935 was about 2,400,000,000 bricks.

Layers and nodules of muddy limestone, the latter termed 'septaria,' are of frequent occurrence. Numerous ammonites and other fossils are usually beautifully preserved in these nodules. The common ammonites in the Oxford Clay are species of *Kosmoceras* and *Quenstedtoceras*. Other invertebrate fossils include the brachiopod *Aulacothyris bernardina*, the oyster *Gryphaea dilatata* and the belemnite *Cylindroteuthis oweni*.

The most interesting fossils from the Oxford Clay are the bones of large extinct reptiles. Numerous genera have been recorded from Peterborough and give a clear picture of the dominant forms of life of the Jurassic period. The chief marine reptiles of Oxfordian times were the plesiosaurs, predaceous feeders with large spike-like teeth. Some of these, such as *Pliosaurus macromerus*, and species of *Cryptocleidus*, *Peloneustes* and *Simolestes*, were relatively short-necked, mostly large-headed forms adapted for rapid progression through the water. Another group of plesiosaurs, represented by the genus *Muraenosaurus*, included slower swimmers which had a small head and a long neck capable of being moved rapidly in any direction. Ichthyosaurs are represented by *Ophthalomosaurus icenicus;* these were rapid swimmers, with no neck and spindle-shaped (or stream-lined) bodies adapted to existence in the open sea. Remains have also been found of *Cetiosaurus leedsi*, a large four-footed dinosaur with a long flexible neck and a small head, which lived in swamps bordering the sea, and fed on aquatic vegetation. The remains of land-forms must have been washed out to sea by rivers, for the bones of *Camptosaurus*, a two-footed herbivorous dinosaur, and of *Omosaurus*, a near relative of the heavily-armoured four-footed *Stegosaurus*, have also been found in the clay at Peterborough.

XI. PLEISTOCENE AND RECENT

OVER the surface of the country is spread a great variety of unconsolidated deposits, many of which are unstratified or but poorly stratified. These superficial deposits are grouped under the general term of 'Drifts,' whereas the beds hitherto described, all either stratified or igneous, are referred to as 'Solid' rocks. The Oxford Clay, the newest Solid formation now surviving in the Central England District, was laid down some 150,000,000 years ago; the Drifts, on the other hand, are of comparatively recent origin—the oldest probably being not more than a million years old. They belong to the Pleistocene and Recent periods. During the vast interval of time between the deposition of the Oxford Clay and the accumulation of the drift deposits, many other beds were laid down, including those of the Cretaceous system, but these have been completely removed by erosion.

The Pleistocene period was marked by a general lowering of temperature, and by the growth of glaciers on mountainous regions. These spread out on to the lowlands and ultimately covered most of N.W. Europe. At times more temperate conditions intervened, and the ice-sheets then became less extensive. The Pleistocene can thus be divided into a series of glacial and interglacial phases.

Much drift was laid down by these Pleistocene ice-sheets. As the ice melted, a vast amount of rock-debris, which had been incorporated in the glaciers both as fine-grained material and as boulders of hard rock, was deposited as a blanket over the country covered by the glaciation.

The ice-sheets tore up rock material from the floor over which they travelled, and re-deposited it elsewhere, sometimes far from its source. Boulders and pebbles transported by glaciers are termed ' glacial erratics.' From the evidence of erratics and of the general constituent materials of boulder-clay, it is possible to deduce the directions from which the various ice-streams came. On the east side of the Warwickshire Coalfield, for instance, Middle Lias debris has been spread over the Lower Lias outcrop, Lower Lias material over Triassic rocks, and Triassic material over the Coal Measures outcrop, from which it is concluded that the ice in this case travelled from the east.

During glacial phases Central England was liable to invasion by ice from three directions; from the Welsh Mountains on the west, from the Irish Sea basin on the north-west, and from the Vale of York and the North Sea basin on the north-east. The deposits left by the Welsh and Irish Sea ice comprise the ' Western Drifts ' of the Midlands; those left by the ice from the north-east, the ' Eastern Drifts.' Central England was invaded by ice on several occasions; Deeley considers that there were three distinct advances of the ice into the Trent valley.

There is at present insufficient evidence to assess the relative importance of the three main sources of ice during each glaciation.

The oldest glacial deposits in Central England comprise the ' High Level Western Drift ' which caps much of the high ground rising over 400 ft. in the Central Midlands. This is characterized by erratics from North Wales. A ' Low-Level Western Drift,' the formation of which was separated from a ' High Level ' by a period of erosion, was largely the product of Irish Sea ice, which originated in the mountains of South-West Scotland and the Lake District, filled up the Irish Sea basin, and ultimately overrode the Cheshire Plain, and penetrated into the heart of the Midlands. Its drifts contain, in addition to Triassic materials, erratics of Scottish and Lake District rocks. Their distribution extends to the east of Birmingham and as far south as Worcester. Broken marine shells, transported by the ice from the floor of the Irish Sea, are sometimes found in the Western Drift. One such occurrence is at Macclesfield; the fact that shells have been carried to 1,280 ft. above sea-level, indicates the height to which the ice piled up, under pressure from the great mass in the Irish Sea basin.

The early invasion of Welsh ice into the West Midlands appears to have been contemporary with the Great Eastern Glaciation of East Anglia. The track of this latter ice-sheet lay along the Cretaceous outcrop; different parts of the glacier, as it moved south and south-west, travelled over different rock formations and consequently the composition of the boulder-clay varies from area to area. In the eastern part of the region, in South Lincolnshire, East Leicestershire, Rutlandshire and Northamptonshire, the boulder-clay contains much Chalk and Jurassic debris and may be termed Chalky-Jurassic boulder-clay. Further west, Triassic material is the common constituent, while there is an intermediate area of Chalky-Jurassic-Triassic boulder-clay.

The Midlands were affected by at least two major glaciations after the retreat of the Great Eastern ice-sheet and its western equivalent; the most recent-looking glacial land forms described below are attributable to the latest of these glacial phases.

Many deposits associated with glaciation are gravelly. During pauses in the recession of the ice, great quantities of outwash material were piled up along the ice-margins. Belts of this morainic material parallel to the original ice-front constitute 'kames.' Streams of melt-water issuing from beneath a retreating ice sheet deposited long trails of sand and gravel at right angles to the ice-front. They are termed eskers or 'ose-trains.' Swellings in these ose-trains mark halt-stages where the sub-glacial streams built up delta-fans. In the area north-west of Wolverhampton stages in the latest retreat of the Irish Sea ice are well marked by kames and oses and by marginal channels cut in high ground by escaping melt-water. During the declining phases of a glaciation melt-water was frequently dammed up, either between separating bodies of ice, or between the retreating ice and high ground, and glacial lakes thus came into existence. Outwash material brought into these lakes was thrown down to form deltas; finer material was sorted from the coarse, and was separately laid down as fine laminated clays. The positions of successive ice-stands near Wolverhampton, and of the Newport and Penkridge ose-trains, traced by E. E. L. Dixon, are shown in the sketch-map, Fig. 16. Plate VIII B is a photograph of a section in glacial outwash gravels which have been contorted by a re-advance of ice.

The deposits of several glacial lakes are known in Central England, where they were first recognized by Jerome Harrison. The more important of these former lakes have been named, for convenience, either after a place or in commemoration of a famous geologist (*e.g.* Lake Lapworth named after Professor Lapworth).

Glacial drifts are responsible for many features of the present topography; indeed, if all the drifts were removed the land would have a very different aspect. Deep hollows in the pre-glacial surface have often been completely filled with drift. Drifts are, therefore, very variable in thickness. Boulder-clay may be 150 ft. thick or more where it fills an early valley, or only a few feet where it covers an original hill-top.

The various types of deposit are often recognizable by the forms of the ground which they constitute. Boulder-clay generally gives rise to a rather featureless undulating topography, but country occupied by glacial gravels is much more diversified, and indeed in the case of the products of the more recent glaciations the land-forms may be a direct indication of the mode of accumulation of the material. Such are the mounds of gravel and sand constituting 'oses' and 'kames' to be seen around Stafford and Wolverhampton.

The heavy glaciation of the Central England district produced numerous changes and apparent abnormalities in the natural drainage system. One of the most interesting of these effects was to change the course of the River Severn. The Upper Severn rises in the Welsh hills and flows north-eastwards to the North Shropshire plain. Instead of continuing northwards, which is the natural direction, it turns abruptly and flows eastwards through Shrewsbury, and then south-eastwards into the Lower Severn basin *via*

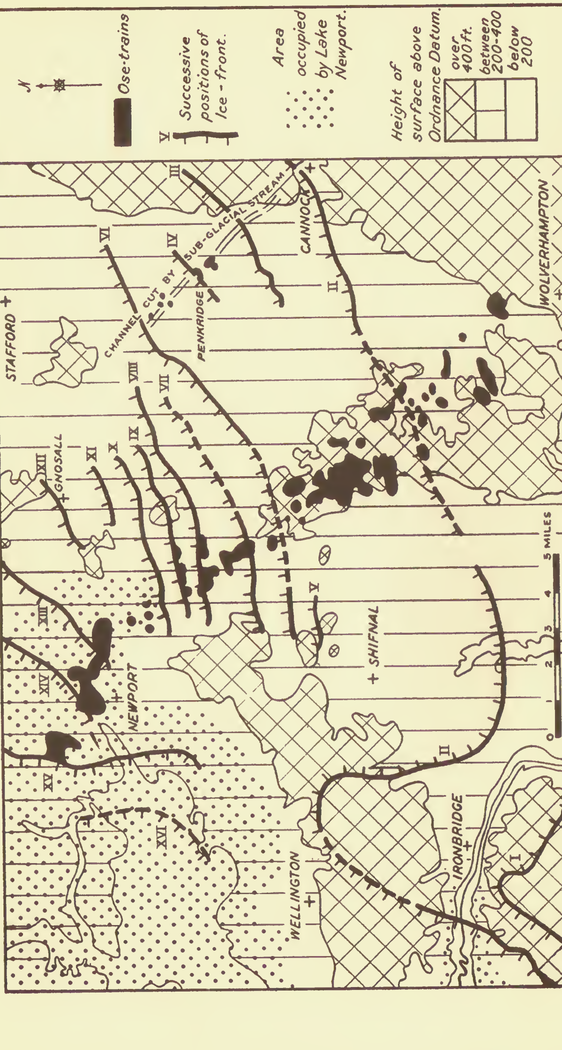


FIG. 16.—*Sketch-map indicating the position of successive ice stands near Wolverhampton, and the Newport Ose-Train.* (Adapted from E. E. L. Dixon and L. J. Wills)

the deep gorge at Ironbridge. In pre-Glacial times the Upper Severn did, in fact, flow northwards, joining the Dee and emptying its waters into the Irish Sea. L. J. Wills has shown that its course was deflected so that it ultimately drained southwards over a former watershed as a result of the following events:

During the north-westward retreat of the Irish Sea ice from the Cheshire Plain, melt-water, including that of the Upper Severn drainage, was impounded between the ice front and the high ground to the south and east, and thus formed two glacier lakes, Lakes Newport and Buildwas, which occupied two embayments of the hills. Their positions are indicated in places by their actual strand-lines which to-day stand some 300 ft. above sea-level. Lake Newport overflowed into the Trent basin at Gnosall; water from Lake Buildwas flowed by way of a col in the watershed at Ironbridge.

With further retreat of the ice the two lakes merged to form Lake Lapworth, and after the fusion, the Ironbridge outlet took all the overflow-water. With the lowering of the overflow-channel by erosion the Ironbridge Gorge was cut, and Lake Lapworth was eventually drained. After the disappearance of the ice, great accumulations of glacial drift on the Cheshire Plain prevented the Upper Severn from following its original course to the Irish Sea, consequently it drained south-eastwards through the Ironbridge Gorge, and maintained this channel long enough to become stabilized. This gorge is illustrated in Plate VIII A.

It should be remarked, however, that R. W. Pocock has noted extensive drift deposits of gravels, sands and loamy clays with boulders in the Worfe basin to the east of the Ironbridge Gorge, all below the 300-ft. level, and that in many places a well-marked feature or ledge runs near the 300-ft. contour. He considers that for a time a lake directly connected with Glacial Lake Buildwas or Glacial Lake Lapworth covered the Worfe basin, and that the combined lake system drained into the Severn at the present outfall of the Worfe with the Severn, or possibly much farther south, by Claverley and Enville, into the Stour Valley.

Melt-water escaping directly from retreating ice-sheets and from glacial lakes gave rise to torrential rivers, which redistributed the accumulations of morainic material and laid it down with little stratifications as fluvio-glacial gravels and sands. Fluvio-glacial gravels pass almost imperceptibly into deposits related to the courses of present rivers.

During interglacial phases, and also after the ice had finally retreated from the district, ancestors of the present rivers continued the re-transportation of glacial drift, re-sorting it and sometimes laying it down on the valley floors as bedded gravels and sands. During the Pleistocene period there were several changes in the relative levels of land and sea. During periods of rising sea-level, accumulation of deposits in the valleys took place; during periods of relative fall, rivers cut their channels deeper, leaving the older deposits at a higher level, and so forming gravel-covered terraces. Several such terraces, at different heights above the present alluvium, are traceable along the valleys of our region. Those in the valley of the Warwickshire Avon are good examples.

Palaeolithic man lived in Central England in interglacial times; hand-axes of Acheulian type have been found in gravels near Coventry.

During the last cold phase of the Pleistocene period, conditions in the Midlands were similar to those of the cold and dry steppe-lands bordering glaciated regions at the present time. Strong winds blowing across the area, caught up the finer parts of the glacial drifts, and gave rise to sandstorms. Blocks of stone lying on the surfaces were etched and polished by sand-blast action, to form wind-faceted pebbles. Many wind-faceted pebbles have been found in the superficial deposits at Lilleshall and around Droitwich.

But little geological change has occurred in Central England during the Recent period. The rivers continue to accumulate alluvial deposits. The low-lying alluvial plain of the Fens, extending into the eastern part of the area, has come into existence. The fens represent an area which was submerged as a result of a gradual local subsidence and which has been subsequently silted up. The Fen Deposits which locally overlie boulder-clay attain a known thickness of about 60 ft. and consist of estuarine silts alternating with peat-beds. In some districts they include marine gravels.

In South Cheshire and Shropshire lakes and meres occupy hollows in the irregular sheet of Drift left by the ice of the last advance from the Irish Sea, and some of them have silted up and been converted into peat-bogs, for example, on Whixall Moor and near Ellesmere, where peat-cutting is an important local industry.

In post-Glacial times the climate has gradually become warmer. Part of the post-Glacial period was characterized by damp conditions which favoured the spread of forests, particularly on the clay-land. The two Jurassic clay belts of the S.E. Midlands were probably wet forest land in immediately prehistoric times, while the intervening outcrop of Jurassic limestones provided a dry natural corridor leading from the south-west of England to Lincolnshire and Yorkshire, which appears to have been used as a traffic route during the Bronze Age, before the clearing of the forests.

Many of the valleys of the Inferior Oolite tracts of Rutlandshire and Northamptonshire which have been eroded into the Upper Lias show the interesting phenomena of ' bulging ' while the intervening ridges are ' cambered.' The exposed clay tends to be forced upward in the narrow valleys, and also, in the wider valleys, to flow laterally in response to downward pressures exerted by the mass of rocks forming the valley sides.

This lateral flow slowly but progressively causes the Oolitic strata, originally flat bedded, to dip towards the nearest valley; the ironstones and limestones of the intervening ridges consequently assume, in generalized cross-section, the form of a modern cambered road. This gradual movement is often accompanied by small-scale faulting.

The face of Central England has, in parts, been considerably altered by the actions of man, largely as a result of the economic value of many of its strata.

The Fens have been drained, and rivers have been diverted, an example of the latter being a diversion of the Trent at Newark, described by R. L. Sherlock, who records that the River Trent at one time flowed past Newark along what is now called the Old Trent Dyke. Later it altered its course and took the present channel, passing some two miles to the north-west of the town, the deserted channel being reduced to a mere ditch. The upper part of the deserted channel has been turned into a canal, and the canal continued across country to the River Devon, which flows past Newark to enter the Trent below the town. A large proportion of the Trent water now flows along the artificial channel.

The extraction of both coal and salt has produced subsidence of land over large areas of the coalfields and saltfields; the excavation of iron ores, for example in Northamptonshire, and of clays for brickmaking, as at Peterborough, has removed many millions of tons of material; artificial hills have been built up of slag from ironworks and waste from coalmines, and extensive caverns have been formed through the mining of limestone, as at Dudley and Ticknall.

Man as a geological agent has been particularly active in the Central England District.

An EXHIBIT illustrating the Geology and Scenery of the district described in this volume is set out on the First Gallery of the Geological Museum, Exhibition Road, South Kensington, London.

XII. GEOLOGICAL SURVEY MAPS AND MEMOIRS[1], AND SHORT BIBLIOGRAPHY OF OTHER WORKS DEALING WITH THE CENTRAL ENGLAND DISTRCIT

MAPS

(*a*) **On Scale of 1 in. to 4 miles:** *Colour-printed;* Solid edition. Out of print.

Sheet 9 and 10, Chester, Shrewsbury. Sheet 11, Derby, Lincoln, Stafford. Sheet 14, Hereford, Clee Hills. Sheet 15, Birmingham, Northampton, Oxford, Worcester.

(*b*) **On Scale of 1 in. to 1 mile:**

(i) *Old Series, hand-coloured*: Out of print.

Sheet 52 N.W., Wellington, Thrapston. Sheet 52 S.W.,* Northampton. Sheet 53 N.W., Coventry, Rugby. Sheet 53 S.E., Towcester. Sheet 54 N.W., Droitwich, Bromsgrove. Sheet 54 N.E., Henley-in-Arden. Sheet 55 N.W., Titterstone Clee Hill. Sheet 55 N.E., Bewdley, Stourport, Kidderminster. Sheet 61 S.W., Church Stretton, Brown Clees. Sheet 61 S.E., Bridgnorth. Sheet 62 N.W.,* Cannock Chase. Sheet 62 N.E.,* Lichfield, Tamworth. Sheet 62 S.W.,* Dudley, Wolverhampton. Sheet 63 N.W., Ashby-de-la-Zouch, Market Bosworth. Sheet 63 S.E., Market Harborough. Sheet 64, Melton Mowbray, Peterborough. Sheet 70, Newark, Corby, Spalding. Sheet 71 S.E.,* Loughborough. Sheet 71 N.E.,* Nottingham. Sheet 71 S.W.,* Derby, Castle Donnington. Sheet 72 N.W.,* Potteries Coalfield. Sheet 72 S.W.,* Stafford. Sheet 72 S.E.,* Burton-on-Trent, Uttoxeter. Sheet 73 N.E.,* Crewe. Sheet 73 S.W.,* Ellesmere, Wem. Sheet 73 S.E.,* Market Drayton, Newport. Sheet 81 S.W., Congleton.

* Largely replaced by New Series Sheets.

(ii) *New Series Sheets, colour-printed*: Drift editions of all sheets and solid editions of sheets marked (s).

Sheet 126, Nottingham, Newark. Sheet 137, Oswestry. Sheet 138, Wem. Sheet 139, Stafford. Sheet 140, Burton upon Trent. Sheet 152, Shrewsbury (s). Sheet 153, Wolverhampton (s). Sheet 154, Lichfield (s). Sheet 155, Atherstone. Sheet 156, Leicester. Sheet 157, Stamford. Sheet 167, Dudley. Sheet 168, Birmingham (s). Sheet 169, Coventry (s). Sheet 171, Kettering. Price 5*s*. each.

(*c*) **On Scale of 6 in. to 1 mile:**

The greater part of the area represented by New Series one-inch maps is also represented on maps of the six-inch scale. These are in manuscript form, and may be consulted in the Library at the Museum of Practical Geology, South Kensington. Copies can be made to special order.

(*d*) **On Scale of 1 in. to 4 miles:** Gravity Survey Overlay.

Sheet 11 (1956), Stockport, Lincoln, Wolverhampton, Stafford, price 5*s*. 6*d*. Sheet 15 (1954), Birmingham, Northampton, Gloucester, Oxford, Worcester, price 5*s*.

MEMOIRS

(a) General Memoirs:

1859. JUKES, J. B.—Geology of the South Staffordshire Coalfield, etc.[2]
1859. HOWELL, H. H.—Geology of the Warwickshire Coalfield.[2]
1860. HULL, E.—Geology of the Leicestershire Coalfield.[2]
1860. AVELINE, W. T., and R. TRENCH.—Geology of part of Northants.[2]

---

[1] Stocks of Survey publications were destroyed by enemy action: all one-inch New Series maps in above list have been reprinted.
[2] Out of print.

1860. AVELINE, W. T., and H. H. HOWELL.—Geology of part of Leicestershire.[2]

1861. AVELINE, W. T.—Geology of parts of Northants and Warwickshire.[2]

1861. AVELINE, W. T.—Geology of the Country around Nottingham.[2]

1869. HULL, E.—Triassic and Permian Rocks of the Midland Counties of England.[2]

1875. JUDD, J. W.—The Geology of Rutland.[2]

1877. SKERTCHLEY, S. B. J.—Geology of the Fenland.[2]

1892–5. FOX-STRANGWAY C., and WOODWARD, H. B.—The Jurassic Rocks of Britain. 5 vols. Jurassi ocks of Central England referred to in vols. iii, iv and v.[2]

1903. BARROW, G.—Geology of the Cheadle Coalfield.[2]

1905. GIBSON, W., C. B. WEDD and OTHERS.—Geology of the North Staffordshire Coalfields.[2]

1907. FOX-STRANGWAYS, C.—Geology of the Leicestershire and South Derbyshire Coalfields[2].

1910. LAMPLUGH, G. W., and W. GIBSON.—Geology of the Country around Nottingham.[2]

1923. KIDSTON R.—Monograph on the Fossil Plants of the Carboniferous Rocks of Great Britain. Vol. II, pt. i.[2]

1927. WHITEHEAD, T. H., T. EASTWOOD, and T. ROBERTSON.—Geology of the southern part of the South Staffordshire Coalfield.[2]

1941. MITCHELL, G. H., and C. J. STUBBLEFIELD.—The Geology of the Leicestershire and South Derbyshire Coalfields. Wartime Pamphlet No. 22[2].

1942. MITCHELL, G. H., C. J. STUBBLEFIELD and R. CROOKALL.—The Geology of the Warwickshire Coalfield. Wartime Pamphlet No. 25[2].

1945. MITCHELL, G. H., C. J. STUBBLEFIELD and R. CROOKALL.—The Geology of the northern part of the South Staffordshire Coalfield. Wartime Pamphlet, No. 43[2].

1955. CROOKALL, R.—Fossil Plants of the Carboniferous Rocks of Great Britain [Second Section] *Mem. Geol. Surv. Palaeont*, vol. iv, pt.i.

(b) New Series Sheet Memoirs:

1900. FOX-STRANGWAYS, C., and W. W. WATTS.—Geology of the Country between Atherstone and Charnwood Forest (Sheet 155).[2]

1902 (3rd edit. 1925). GIBSON, W., and OTHERS.—Geology of the Country around Stoke-upon-Trent (Sheet 123).[2]

1903. FOX-STRANGWAYS, C.—Geology of the Country near Leicester (Sheet 156).[2]

1905. FOX-STRANGWAYS, C.—Geology of the Country between Derby, Burton-on-Trent, Ashby-de-la-Zouch, and Loughborough (Sheet 141).[2]

1906. POCOCK, T. I.—Geology of the Country around Macclesfield, Congleton, Crewe and Middlewich (Sheet 110).[2]

1908. LAMPLUGH, G. W., and OTHERS.—Geology of the Country between Newark and Nottingham (Sheet 126).[2]

1908. GIBSON, W., T. I. POCOCK and OTHERS.—Derbyshire and Nottinghamshire Coalfield (Sheet 125).[2]

1909. GIBSON, W., and OTHERS.—Geology of the Melton Mowbray District and S.E. Notts (Sheet 142).[2]

1919. BARROW, G., and OTHERS.—Geology of the Country around Lichfield, etc. (Sheet 154).

1923. EASTWOOD, T., and OTHERS.—Geology of the Country around Coventry (Sheet 169).

1925. EASTWOOD, T., T. H. WHITEHEAD, and T. BOBERTSON.—Geology of the Country around Birmingham (Sheet 168).[2]

1925. POCOCK, R. W., and D. A. WRAY.—Geology of the Country around Wem (Sheet 138).[2]

1927. WHITEHEAD, T. H., and OTHERS.—Country between Stafford and Market Drayton (Sheet 139).[2]

1928. WHITEHEAD, T. H., E. E. L. DIXON, and OTHERS.—Country between Wolverhampton and Oakengates (Sheet 153).[2]

1938. POCOCK, R. W., T. H. WHITEHEAD, and OTHERS.—Geology of the Country around Shrewsbury (Sheet 152).[2]

1947. POCOCK, R. W., and T. H. WHITEHEAD.—Geology of the Country around Dudley (Sheet 167).

1955. STEVENSON, I. P., and G. H. MITCHELL.—Geology of the Country between Burton upon Trent, Rugeley and Uttoxeter (Sheet 140).

[2] see second footnote on p. 76

(c) Economic Memoirs:

Water Supply:

1909. WOODWARD, H. B., and B. B. THOMPSON.—Water Supply of Bedfordshire and Northants[2].
1914. LAMPLUGH, G. W., and B. SMITH.—Water Supply of Nottinghamshire.
1928. RICHARDSON, L.—Wells and Springs of Warwickshire[2].
1930. RICHARDSON, L.—Wells and Springs of Worcestershire[2].
1931. RICHARDSON, L.—Wells and Springs of Leicestershire[2].
1942. WOODLAND, A. W.—Water Supply from Underground Sources of the Oxford-Northampton District. Wartime Pamphlet No. 4, Pt. I[2].

Mineral Resources:

1915 2nd edit. 1918 by SHERLOCK, R. L., and B. SMITH; 3rd edit. 1939 by SHERLOCK, R. L., and S. E. HOLLINGWORTH.—Gypsum and Anhydrite. Spec. Rep. Min. Resources of Great Britain. Vol. iii.[2]
1918 (2nd edit. 1920).—Refractory Materials: Ganisters. Spec. Rep. Min. Resources of Great Britain. Vol. vi.[2]
1920. LAMPLUGH, G. W., C. B. WEDD, and J. PRINGLE.—Iron Ores: Bedded Ores of the Lias, Oolites and Later Formations in England. Spec. Rep. Min. Resources of Great Britain. Vol. xii.[2]
1920. STRAHAN, A., and OTHERS.—Iron Ores: Pre-Carboniferous and Carboniferous Bedded Ores of England and Wales. Spec. Rep. Min. Resources of Great Britain. Vol. xiii.[2]
1920. CANTRILL, T. C., and OTHERS.—Refractory Materials: Fireclays. Spec. Rep. Min. Resources of Great Britain. Vol. xiv.[2]
1921. SHERLOCK, R. L.—Rock-Salt and Brine. Spec. Rep. Min. Resources of Great Britain. Vol. xviii.[2]
1925. DEWEY, H., T. EASTWOOD, and OTHERS.—Copper Ores of the Midlands. Spec. Rep. Min. Resources of Great Britain. Vol. xxx.

Other Economic Memoirs:

1949. TAYLOR, J. H.—Petrology of the Northampton Sand Ironstone Formation.
1951. HOLLINGWORTH, S. E., and J. H. TAYLOR.—The Northampton Sand Ironstone: Stratigraphy, Structure and Reserves.
1952. WHITEHEAD, T. H., and OTHERS.—The Liassic Ironstones.

SHORT BIBLIOGRAPHY OF OTHER WORKS

General:

1686. PLOT, R.—Natural History of Staffordshire.
1898. LAPWORTH, C., W. W. WATTS and W. J. HARRISON.—Sketch of the Geology of the Birmingham District. *Proc. Geol. Assoc.*, vol. xv, p. 315.
1910. VARIOUS AUTHORS.—Geology in the Field, *Geol. Assoc. Jubilee Vol.* (Northants and Warw., p. 450; Notts, p. 518, Staffs. p. 564; Shropshire, p. 739; Charnwood, p. 770).
1913. SMITH, B.—The Geology of the Nottingham District. *Proc. Geol. Assoc.*, vol. xxiv, p. 205.
1922. SHERLOCK, R. L.—Man as a Geological Agent. London.
1925. WATTS, W. W., and OTHERS.—The Geology of South Shropshire. *Proc. Geol. Assoc.* vol. xxv, p. 321.
1925. FLEET, W. F.—The Chief Heavy Detrital Minerals in the Rocks of the English Midlands. *Geol. Mag.*, p. 98.
1925. RASTALL, R. H.—The Tectonics of the Southern Midlands. *Geol. Mag.*, p. 193.
1926. LOWE, E. E.—Igneous Rocks of the Mount Sorrel District. *Publ. Leics. Lit. and Phil. Soc.*
1928. MCLINTOCK, W. F. P., and J. PHEMISTER.—A Gravitational Survey over the Swynnerton Dyke, Staffs. Summary of Progress, *Geol. Surv.* (for 1927), p. 44.
1929. SHOTTON, F. W.—The Geology of the Country around Kenilworth. *Quart. Journ. Geol. Soc.*, vol. lxxxv, p. 167.
1935. WILLS, L. J.—An Outline of the Palaeogeography of the Birmingham Country. *Proc. Geol. Assoc.*, vol. xlvi, p. 211.
1942. MARSHALL, C. E.—Field Relations of certain of the Basic Igneous Rocks associated with the Carboniferous Strata of the Midland Counties. *Quart. Journ. Geol. Soc.*, vol. xcviii, p. 1.
1944. HOLLINGWORTH, S. E., J. H. TAYLOR and G. A. KELLAWAY.—Large-scale Superficial Structures in the Northampton Ironstone Field. *Quart. Journ. Geol. Soc.*, vol. c, p. 1.
1946. MARSHALL, C. E.—The Barrow Hill Intrusion of South Staffordshire. *Quart. Journ. Geol. Soc.*, vol. ci, p. 197.

[2] see second footnote on p. 76

Pre-Cambrian System:

1896. WATTS, W. W.—Notes on the Ancient Rocks of Charnwood Forest. *Geol. Mag.*, dec. 4, vol. iii, p. 485.
1928. BENNETT, F. W., E. E. LOWE, H. H. GREGORY, and F. JONES.—The Geology of Charnwood Forest. *Proc. Geol. Assoc.*, vol. xxxix, p. 241.
1934. WILLS, L. J., and F. W. SHOTTON.—New sections showing the Junction of the Cambrian and Pre-Cambrian at Nuneaton. *Geol. Mag.*, vol. lxxi, p. 512.
1958. FORD, T. D.—Pre-Cambrian Fossils from Charnwood Forest. *Proc. Yorks. Geol. Soc.*, vol. xxxi., p. 211.

Cambrian System:

1879. ALLPORT, S.—On the Diorites of the Warwickshire Coalfield. *Quart. Journ. Geol. Soc.*, vol. xxxv, p. 637.
1886. LAPWORTH, C.—On the Sequence and Systematic Position of the Cambrian Rocks of Nuneaton. *Geol. Mag.*, dec. 3, vol. iii, p. 319.
1916. ILLING, V. C.—The Paradoxidian Fauna of the Stockingford Shales. *Quart. Journ. Geol Soc.*, vol. lxxi for 1915, p. 386.
1946. BUTTERLEY, A. D. and G. H. MITCHELL.—Driving of Two Drifts by the Desford Coal Co. Ltd., at Merry Lees, Leicestershire. *Trans. Inst. Mining Eng.*, vol. civ, p. 703.

Silurian and Devonian Systems:

1912. KING, W. W., and W. J. LEWIS.—The Uppermost Silurian and Old Red Sandstone of South Staffordshire. *Geol. Mag.*, dec. 5, vol. ix, p. 437.
1924. WILLS, L. J., and OTHERS.—The Upper Llandovery Series of Rubery. *Proc. Birm. Nat. Hist. Phil. Soc.*, vol. xv, p. 67.
1925. KING, W. W.—Notes on the 'Old Red Sandstone' of Shropshire. *Proc. Geol. Assoc.*, vol. xxxvi, p. 383.
1934. KING, W. W.—The Downtonian and Dittonian Strata of Great Britain and North-Western Europe. *Quart. Journ. Geol. Soc.*, vol. xc, p. 526.
1936. BUTLER, A. J., and K. P. OAKLEY.—Report of 'Coral Reef' Meeting in Dudley District. *Proc. Geol. Assoc.* vol. xlvii, p. 133.
1939. BUTLER, A. J.—The Stratigraphy of the Wenlock Limestone of Dudley. *Quart, Journ. Geol. Soc.*, vol. xcv, p. 37.
1952. WHITTARD, W. F.—A Geology of South Shropshire, *Proc. Geol. Assoc.*, vol. lxiii, p. 143.

Carboniferous System:

1840. PRESTWICH, J.—On the Geology of Coalbrookdale. *Trans. Geol. Soc.*, ser. 2, vol. v. p. 413.
1862. HULL, E.—On Iso-diametric Lines . . . with special reference to the Carboniferous Rocks of Britain. *Quart. Journ. Geol. Soc.*, vol. xviii, p. 127.
1864. HULL, E., and A. H. GREEN. On the Millstone Grit of North Staffordshire, etc. *Quart. Journ. Geol. Soc.*, vol. xx, p. 243.
1890–1. KIDSTON, R.—On the Fossil Flora of the Staffordshire Coalfields, Pt. I. *Trans. Roy. Soc. Edin.*, vol. xxxv, p. 317; Pt. 2, *op. cit.*, vol. xxxvi, p. 63.
1906. COCKIN, G. M.—On the Occurrence of Limestone of the Lower Carboniferous Series in the S. Staffs Coalfields. *Quart. Journ. Geol. Soc.*, vol. lxii, p. 523.
1912. VERNON, R. D.—The Geology and Palaeontology of the Warwickshire Coalfield. *Quart. Journ. Geol. Soc.*, vol. lxviii, p. 587.
1917. KIDSTON, R., T. C. CANTRILL, and E. E. L. DIXON.—The Forest of Wyre and Titterstone Clee Hill Coalfields, *Trans. Roy. Soc. Edin.*, vol. li, p. 999.
——. PARSONS, L. M.—The Carboniferous Limestone bordering the Leicestershire Coalfield. *Quart. Journ. Geol. Soc.*, vol. lxxiii, p. 84.
1921. KING, W. W.—The Plexography of South Staffordshire in Avonian Time. *Trans. Inst. Min. Eng.*, vol. lxi, p. 151.
1926. POCOCK, R. W.—The Basalt of Little Wenlock. *Sum. Prog. Geol. Surv.* (for 1925), p. 140.
1931. POCOCK, R. W.—The Age of the Midland Basalts. *Quart. Journ. Geol. Soc.*, vol. lxxxvii, p. 1.
——. DIX, E.—The Flora of the Upper Portion of the Coal Measures of North Staffordshire. *Quart. Journ. Geol. Soc.*, vol. xxxvii, p. 160.
1932. HESTER, S. W.—The Millstone Grit Succession in North Staffordshire. *Sum. Progr. Geol. Surv.* (for 1931), p. 34.
1933. FEARNSIDES, W. G.—A Correlation of Structures in the Coalfields of the Midland Province. *Rep. Brit. Assoc.*, p. 57.
1941. MITCHELL, G. H., and C. J. STUBBLEFIELD.—The Carboniferous of Breedon Cloud, Leicestershire, and the associated Inliers. *Geol. Mag.*, vol. lxxviii, p. 201.
1957. STUBBLEFIELD, C. J. and F. M. TROTTER.—Divisions of the Coal Measures on Geological Survey Maps of England and Wales, *Bull. Geol. Surv. Gt. Brit.*, No. 13, p. 1.

Enville Beds and the Permian System:

1889. KING, W. W.—The Permian Conglomerates of the Lower Severn Basin. *Quart. Journ. Geol. Soc.*, vol. lv, p. 97.
1924. BOULTON, W. S.—On a recently discovered breccia-bed underlying Nechells (Birmingham), etc. *Quart. Journ. Geol. Soc.*, vol. lxxx, p. 343.
1927. SHOTTON, F. W.—The Conglomerates of the Enville Series of the Warwickshire Coalfield. *Quart. Journ. Geol. Soc.*, vol. lxxxiii, p. 604.
1933. BOULTON, W. S.—The Rocks between the Carboniferous and the Trias in the Birmingham District. *Quart. Journ. Geol. Soc.*, vol. lxxxix, p. 58.

Triassic System:

1903. SHRUBSOLE, O. A.—On the probable source of some of the pebbles of the Triassic Pebble Beds . . . of the Midlands. *Quart. Journ. Geol. Soc.*, vol. lix, p. 311.
——. WATTS, W. W.—Charnwood Forest. A Buried Triassic Landscape. *Geographical Journ.*, vol. xxi, p. 623.
1910. WILLS, L. J.—The Fossiliferous Lower Keuper Rocks of Worcestershire. *Proc. Geol. Assoc.*, vol. xxi, p. 249.
——. SMITH, B.—The Upper Keuper Sandstones of East Nottinghamshire. *Geol. Mag.*, dec. 5, vol. vii, p. 302.
1912. BOSWORTH, T. O.—The Keuper Marls around Charnwood. *Publ. by Leic. Lit. and Phil. Soc.*
1912. MATLEY, C. A.—The Upper Keuper (Arden) Sandstone Group, etc., of Warwickshire. *Quart. Journ. Geol. Soc.*, vol. lxviii, p. 252.
1926. SHERLOCK, R. L.—A Correlation of the British Permo-Triassic Rocks, pt. 1. *Proc. Geol. Assoc.*, vol. xxvii, p. 1.
1928. SHERLOCK, R. L.—Ditto, pt. 2. *Proc. Geol. Assoc.*, vol. xxxix, p. 49.

Jurassic System:

1876. HARRISON, W. J.—On the occurrence of Rhaetic Beds in Leicestershire. *Quart. Journ. Geol. Soc.*, vol. xxxii, pp. 212–218.
1910–13. ANDREWS, C. W.—Descriptive Catalogue of the Marine Reptiles of the Oxford Clay, vol. i. *Brit. Mus.* (*Nat. Hist.*) *Cat.*
1912. RICHARDSON, L.—On the Rhaetic of Warwickshire. *Geol. Mag.*, dec. 5, vol. ix, p. 24.
1920. COX, A. H., and A. E. TRUEMAN.—Intra-Jurassic Movements and Underground Structure of the Southern Midlands. *Geol. Mag.*, vol. lvii, pp. 198–208.
1921–28. THOMPSON, BEEBY.—The Northampton Sand of Northamptonshire. *Journ. Northants. N.H.S.*; and numerous other papers.
1923. RICHARDSON, L.—Certain Jurassic (Aalanian-Vesulian) Strata of Southern Northamptonshire. *Proc. Geol. Assoc.*, vol. xxxiv, pp. 97–113.
1925. NEAVERSON, E.—Zones of the Oxford Clay near Peterborough. *Proc. Geol. Assoc.*, vol. xxxvi, pp. 27–37.
1933. ARKELL, W. J.—The Jurassic System in Great Britain. *The Clarendon Press, Oxford.*
1937. KENT, P. E.—The Lower Lias of South Nottinghamshire. *Proc. Geol. Assoc.*, vol. xlviii, p. 163.
1938. RICHARDSON, L., and P. E. KENT.—Weekend Field Meeting in the Kettering District. *Proc. Geol. Assoc.*, vol. xlix, pp. 59–76.
1942. SPATH, L. F.—The Ammonite Zones of the Lias. *Geol. Mag.*, vol. lxxix, pp. 264–268.
1946. HOLLINGWORTH, S. E., and J. H. TAYLOR.—An Outline of the Geology of the Kettering District. *Proc. Geol. Assoc.*, vol. lvii, p. 204.

Pleistocene and Recent:

1886. DEELEY, R. M.—The Pleistocene Succession in the Trent Basin. *Quart. Journ. Geol. Soc.*, vol. xlii, p. 437.
1898. HARRISON, W. J.—The Ancient Glaciers of the Midland Counties of England. *Proc. Geol. Assoc.*, vol. xv, p. 400.
1924. WILLS, L. J.—The Development of the Severn Valley in the Neighbourhood of Ironbridge and Bridgnorth. *Quart. Journ. Geol. Soc.*, vol. lxxx, p. 274.
1925. TOMLINSON, M. E.—The River Terraces of the Lower Valley of the Warwickshire Avon. *Quart. Journ. Geol. Soc.*, vol. lxxxi, p. 137.
1935. TOMLINSON, M. E.—The Superficial Deposits of the Midlands. *Quart. Journ. Geol. Soc.*, vol. xci, p. 423.
1937. WILLS, L. J.—The Pleistocene History of the West Midlands (*Pres. Address to Section C*). *Rep. Brit. Assoc. Adv. of Science*, p. 71.
1938. WILLS, L. J.—The Pleistocene Development of the Severn from Bridgnorth to the Sea. *Quart. Journ. Geol. Soc.*, vol. xciv, p. 161.
1953. SHOTTON, F. W.—The Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing upon the topographic development of the Midlands. *Phil. Trans. Roy. Soc.*, ser. B., vol. ccxxxvii, p. 209.

Printed in England under the authority of Her Majesty's Stationery Office
by A. Wheaton & Co., Ltd., Exeter.
P.S. 204492/2000 Wt. 3092 K16 10/62 A. W. & Co., Ltd. GP943

LIST OF HANDBOOKS ON THE REGIONAL GEOLOGY OF GREAT BRITAIN

ENGLAND AND WALES:

Northern England (*3rd Edition*, 1953) . .	5*s*. 0*d*. (5*s*. 5*d*.)
London and Thames Valley (*3rd Edition*, 1960)	5*s*. 0*d*. (5*s*. 5*d*.)
Central England District (*2nd Edition*, 1947) .	6*s*. 0*d*. (6*s*. 5*d*.)
East Yorkshire and Lincolnshire (1948) . .	5*s*. 0*d*. (5*s*. 6*d*.)
The Wealden District (*3rd Edition*, 1954) . .	5*s*. 0*d*. (5*s*. 6*d*.)
The Welsh Borderland (*2nd Edition*, 1948) .	6*s*. 0*d*. (6*s*. 6*d*.)
South-West England (*2nd Edition*, 1948) . .	6*s*. 0*d*. (6*s*. 6*d*.)
Hampshire Basin and Adjoining Areas (*3rd Edition*, 1960)	6*s*. 0*d*. (6*s*. 6*d*.)
East Anglia and Adjoining Areas (*4th Edition*, 1961)	6*s*. 0*d*. (6*s*. 6*d*.)
South Wales (*2nd Edition*, 1948) . . .	6*s*. 0*d*. (6*s*. 6*d*.)
North Wales (*3rd Edition*, 1961) . . .	6*s*. 0*d*. (6*s*. 7*d*.)
The Pennines and Adjacent Areas (*3rd Edition*, 1954)	6*s*. 0*d*. (6*s*. 6*d*.)
Bristol and Gloucester District (*2nd Edition*, 1948)	6*s*. 0*d*. (6*s*. 6*d*.)

SCOTLAND:

Grampian Highlands (*2nd Edition*, 1948) . .	5*s*. 0*d*. (5*s*. 6*d*.)
Northern Highlands (*3rd Edition*, 1960) . .	5*s*. 0*d*. (5*s*. 6*d*.)
South of Scotland (*2nd Edition*, 1948) . .	6*s*. 0*d*. (6*s*. 6*d*.)
Midland Valley of Scotland (*2nd Edition*, 1948)	6*s*. 0*d*. (6*s*. 7*d*.)
Tertiary Volcanic Districts (*3rd Edition*, 1961) .	6*s*. 0*d*. (6*s*. 7*d*.)

Prices in brackets include postage

The handbooks are obtainable from the Museum of Practical Geology, Exhibition Road, South Kensington, S.W.7, and from

HER MAJESTY'S STATIONERY OFFICE

AT THE ADDRESSES OVERLEAF OR THROUGH ANY BOOKSELLER

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

S.O. Code No. 62-343-0-6